# Federation Affairs

## Minutes of the First Meeting of the Federation of Sewage Works Associations

### The Board of Control

The Board of Control of the Federation of Sewage Works Associations held a meeting on October 16, 1928, at 12:30 p.m. in The Stevens Hotel, Chicago, Illinois. Chairman C. A. Emerson, Jr., presided.

The Secretary called the roll which showed the following members of the Board to be present:

V. M. Ehlers, Austin, Texas
C. A. Emerson, Jr., Philadelphia, Penna. (Chairman)
Lewis Finch, Indianapolis, Indiana
Max Levine, Ames, Iowa
H. E. Moses, Harrisburg, Penna. (Secretary-Treasurer)
W. J. Orchard, Newark, New Jersey
Miss J. H. Rider, Tucson, Arizona
H. W. Streeter, Cincinnati, Ohio
L. F. Warrick, Madison, Wisconsin
Abel Wolman, Baltimore, Maryland (Vice-Chairman)
H. E. Miller, Raleigh, North Carolina

By proxy to Abel Wolman:

Kenneth Allen, New York
F. H. Dryden, Salisbury, Maryland
C. C. Kennedy, San Francisco, California

By proxy to H. E. Miller:

W. M. Piatt, Durham, North Carolina

Also present:

William W. Buffum, New York (Business Manager)
F. W. Mohlman, Chicago (Editor)

A short discussion took place concerning the status as to eligibility for membership in the Federation of a combined waterworks and sewage association. No formal action was taken, but it was the sense of the Board that the members of such combined associations primarily interested in sewage would form a separate group that would be eligible for affiliation with the Federation.

The Board proceeded to consider the revised draft of the Constitution and By-Laws, as printed in October, 1928, issue of Sewage Works Journal.

Each section was read and upon motion, which was seconded and carried, was either approved as read or amended as noted below. Finally upon motion by Mr. Orchard, seconded by Mr. Miller, which carried, the Constitution and By-Laws as amended were adopted.

The Constitution and By-Laws, with amendments as noted and as finally adopted, are as follows:

CONSTITUTION

Constitution adopted without amendment.

BY-LAWS

Article I—No amendments.

Article II—No amendments.

Article III—Section 1—Add the words "together with five members-at-large selected at their first meeting by a two-thirds vote of such representatives."

Article III—Section 2—Omit the following words, "but no person shall be selected to serve for more than two consecutive years."

Article III—Section 3—After the words "by a two-thirds vote of the members of the Board present" add the words "and voting."

Article III—Section 4—No amendments.

Article IV—Section 1—Change the third line to read, "They shall serve without compensation and their term of office shall be as provided in Section 5 of this Article."

Article IV—Sections 2, 3, 4, 5—No amendments.

Article V—Sections 1 and 2—No amendments.

Article V—Section 3—Insert after the words "Secretary-Treasurer" the words "and Editor."

Article VI—Sections 1, 2, 3, 4, 5, 6, 7—No amendments.

Article VII—Sections 1, 2, 3, 4, 5, 6—No amendments.

Article VII—Section 7—Entire section eliminated.

Article VIII—After the words "members of the Board present" add the words "and voting.'

Upon motion, seconded and carried, the following were elected as Members-at-Large:

W. J. Orchard, Newark, New Jersey
William W. Buffum, New York City
Kenneth Allen, New York City
John R. Downes, Bound Brook, New Jersey
H. W. Streeter, Cincinnati, Ohio

By motion, seconded and carried, the personnel of the Executive, Membership, Publication, Coördination and Research Committees was approved as follows:

*Executive Committee*

*Chairman, Vice-Chairman and Secretary-Treasurer, ex-officio members—*
V. M. Ehlers, Texas
W. J. Orchard, New Jersey

*Membership Committee*

H. W. Streeter, Ohio

G. L. Davenport, California
H. E. Miller, North Carolina

*Publication Committee*

*Editor, ex-officio*
J. R. Downes, New Jersey
W. T. Knowlton, California
W. M. Piatt, North Carolina
Jane Rider, Arizona

*Coördination Committee*

Kenneth Allen, New York
F. H. Dryden, Maryland
Lewis Finch, Indiana

*Research Committee*

Max Levine, Iowa
W. S. Mahlie, Texas
J. J. Hinman, Iowa
L. F. Warrick, Wisconsin
C. C. Kennedy, California

The Board considered the eligibility of various associations seeking membership in the Federation as to harmony of their respective constitutions with that of the Federation. As provided in By-Laws—Article I, Section 1, and upon motion of Mr. Orchard, seconded by Mr. Warrick, which carried, the following organizations were elected to membership in the Federation when they shall have accepted the Constitution and By-Laws of the Federation:

Arizona Sewage Works Association
California Sewage Works Association
Central States Sewage Works Association
    Illinois
    Wisconsin
    Indiana
Iowa Wastes Disposal Association
Maryland Water and Sewerage Association
North Carolina Sewage Works Association
Pennsylvania Sewage Works Association
Texas Sewage Works Association

Mr. Buffum verbally reported concerning difficulties he was experiencing with the postal authorities in connection with postal rates. After discussion of the matter it was moved by Mr. Orchard, seconded by Mr. Streeter, that the Editor and Secretary be empowered annually to compile, print and mail a list of members in good standing and that a charge of one dollar be made for this publication to all subscribers who are not members of local associations affiliated with the Federation. Carried.

On motion by Mr. Orchard, seconded by Mr. Wolman, which carried, the Board passed the following resolution: Resolved that the Board of

Control at its first meeting extend to Chairman Emerson its appreciation of his efforts in organizing the Federation.

Messrs. Buffum and Orchard spoke briefly concerning need for advertising matter, also asking the board members to suggest names of possible subscribers—not members of associations.

The Secretary was instructed to send a letter to The Chemical Foundation expressing the appreciation of the Federation for the invaluable help of the Foundation in furthering the progress of the Federation.

The Secretary-Treasurer read the following report which on motion was accepted and ordered to be filed:

### *Report of Secretary-Treasurer*
### *Federation of Sewage Works Associations*

Harrisburg, Penna., October 11th, 1928.

Mr. C. A. Emerson, Jr.
Chairman, Federation of Sewage Works Associations,
Philadelphia, Penna.

Dear Mr. Emerson:

I take this opportunity of making a brief report concerning membership in the Federation as of date of October 11th, 1928.

The Secretary has received membership lists and checks covering the same at $1.00 per member, except as noted in the case of the Central States Sewage Works Association, as follows:

| *Name of Association* | *Number of Members* |
|---|---|
| Arizona Sewage Works Association | 15 |
| California Sewage Works Association | 85 |
| Central States Sewage Works Association | 54* |
| Illinois | |
| Indiana | |
| Wisconsin | |
| Maryland Water & Sewage Association | 35 |
| Pennsylvania Sewage Works Association | 84 |
| Total Membership | 273 |

* Fifty-four names forwarded; only $51.00 paid.

Upon assuming my duties as Secretary-Treasurer, I opened an account for the Federation in that capacity with the Union Trust Company of Pennsylvania at Harrisburg, Pennsylvania. Later you informed me that all of the financial dealings would be handled in the office of William W. Buffum, Business Manager, and thereafter I merely received checks for dues, endorsed them and forwarded them to Mr. Buffum. My account with the Union Trust Company has been balanced and I have no money

belonging to the Federation in my hands at the present time.

Very truly yours,
H. E. Moses,
Secretary-Treasurer.

No further business, the Board adjourned.

(Signed)
H. E. Moses,
Secretary-Treasurer.

---

## Sewage Works Conference Groups

### New Jersey

About twenty persons, members of the New Jersey Sewage Works Association, have formed a "Sewage Conference Group" to take advantage of the privileges extended by the Sewage Works Federation. This conference group plans to meet during the annual meetings of the New Jersey Sewage Works Association held every spring. Those who are members of the New Jersey Sewage Works Association may join by writing Dr. W. Rudolfs, Short Course Building, New Jersey Agricultural Experiment Station, New Brunswick, New Jersey.

### New England

A "Sewage Conference Group" similar to the New Jersey group was organized in Boston at the most recent meeting of the Sanitary Engineering Division of the Boston Society of Civil Engineers. Approximately thirty residents of Boston and vicinity have joined the group. A committee has been formed for the purpose of extending the membership. The Chairman of the committee is Stuart E. Coburn, Metcalf and Eddy, Statler Building, Boston. Residents of New England who desire information concerning the aims and functions of this group should communicate with Mr. Coburn.

# Sewage Research

## Experiments on the Dewatering of Sewage Sludge with a Centrifuge

By C. E. Keefer[1] and Herman Kratz, Jr.[2]

### Synopsis

Sludge is dewatered at most sewage works in the United States on drying beds of sand or similar material. The wet sludge, usually after digestion, is applied to these beds, and dries by drainage and evaporation. This method is subject to climatic conditions, and furthermore increases the possibility of producing an aerial nuisance, principally when the sludge to be dried is not thoroughly digested. Another method of dewatering sludge, which has been used in Germany for a number of years, is by centrifuges, which operate automatically. They have been considered expensive to operate and therefore have never been used in the United States except for demonstration purposes. The first of these machines was known as the Schaefer-ter-Meer centrifuge. In 1913 these centrifuges were completely remodeled and improved. One of them was shipped to Milwaukee in 1920 where it was used for dewatering activated sludge.

**Centrifuge at Baltimore.**—Additional sludge drying beds were needed at the Baltimore sewage works in 1921. About this time an opportunity was afforded to test the centrifuge in Baltimore in comparison with sludge drying beds. Experiments were carried on for several months in 1921, and were supplemented by additional tests in 1924 and 1925 with an improved type of centrifuge. The purpose of this paper is to describe in detail the operation of the centrifuge, and to give the data of the experiments. Furthermore, estimates are presented comparing the cost of drying sludge on sand beds and by centrifuges, together with the advantages and disadvantages of each method.

### Introduction

Practically all of the sludge at the Baltimore sewage works is dried on sand beds. This method of treatment has been used since the plant was put in operation in 1912. Up until 1921 an area of 7.57 acres of sludge drying beds had been constructed at an approximate cost of $43,600.

[1] *Engineer of Sewage Disposal.*
[2] *Junior Chemist, Bureau of Sewers, Baltimore, Md.*

This area was insufficient to dry all of the sludge, and the construction of more drying beds was contemplated. About this time the Milwaukee Sewerage Commission was conducting experiments on the dewatering of activated sludge with a centrifuge, made by the Hanomag Company of Hanover, Germany. Negotiations were made with the representatives of this company, and they agreed to furnish a centrifuge for experimental work. This machine was delivered to the Baltimore sewage works, and assembled during the latter part of 1921. Before discussing these experiments a brief résumé of the history of the centrifuge will be given.

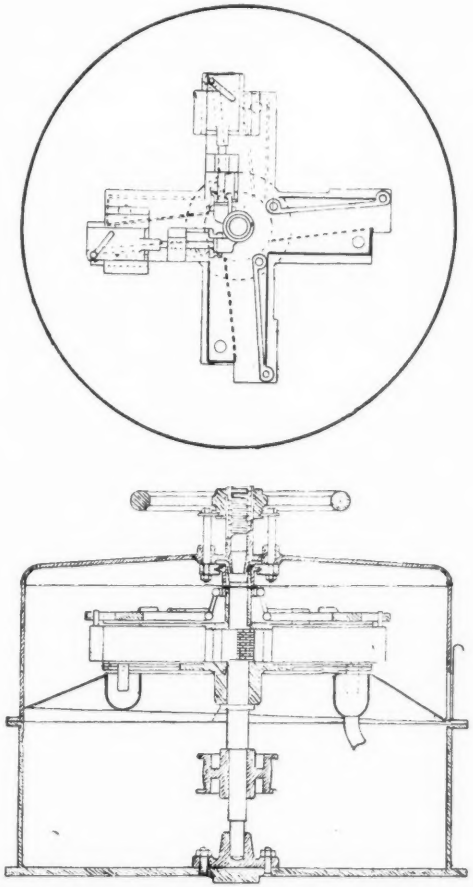


FIG. 1.—Sectional View of First Schaefer Centrifuge.

**Historical Summary.**—Centrifugal machines have been used for a number of years in sugar, oil, and other industries to separate solids from liquids. Perhaps the first attempt ever made to use centrifuges for dewatering sewage sludge was by Herman Schaefer at Cologne, Germany, about 1902 or 1903. He built a centrifuge, which consisted of four separate prismatic compartments contained within an outer housing. These compartments (see Figure 1) were arranged to form a cross, each arm of which comprised an independent and separate chamber. In each compartment there was a

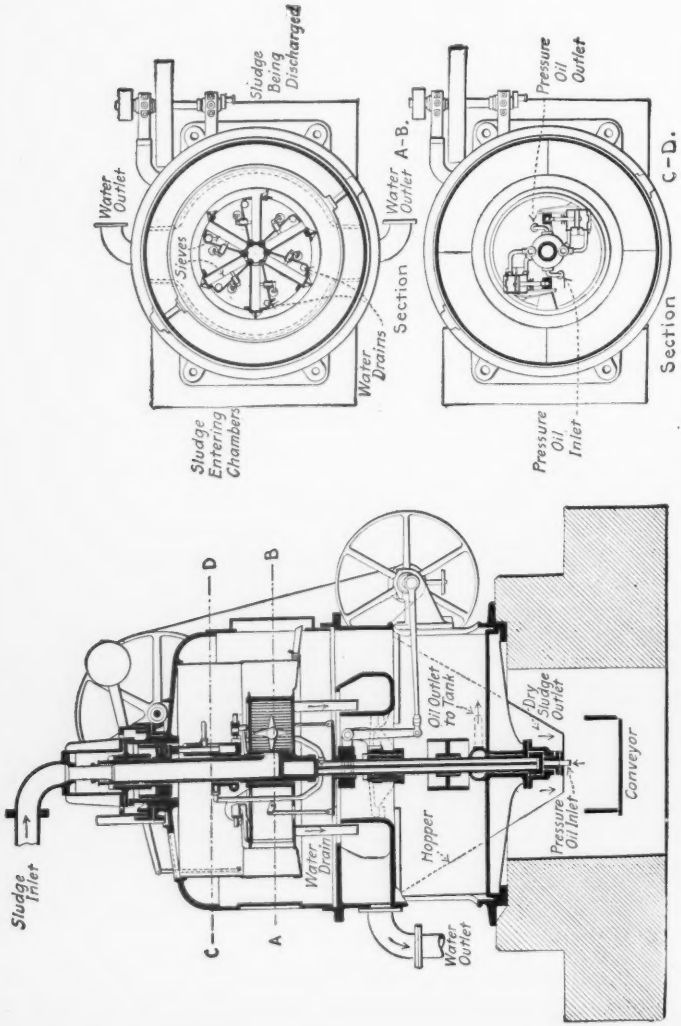



FIG. 2.—Sectional Views of Second Schaefer-ter-Meer Centrifuge. (Courtesy of Metcalf and Eddy, "American Sewerage Practice," Vol. III, 1916, McGraw-Hill Book Co., Inc.)

closely woven radial sieve in a vertical position. The sludge flowed into the compartments through a hollow shaft. The liquid was forced through the sieves by centrifugal action, then down a vertical pipe and out of the centrifuge. One side of each compartment was movable, and after a definite number of rotations, these sides automatically opened and allowed the dried sludge to be thrown against the outer casing of the centrifuge.

After Schaefer had worked with his machine for several months, he finally communicated with Dr. Gustav ter-Meer in 1904, who was then chief engineer of the George Egestorff Company of Hanover-Linden, Germany. This company is now the Hanomag Company, of which Dr. ter-Meer is the principal director. With the latter's advice and supervision a second centrifuge was designed and built. This machine, which was later known as the Schaefer-ter-Meer centrifuge, was erected at Frankfort-on-the-Main, and was subjected to a series of tests lasting for two years. During this time many changes and improvements were made. Figure 2 shows cross-sections of the machine as it was finally built. In this machine the sludge flowed into the centrifuge through a vertical hollow shaft, around which there were six radial compartments instead of four as in the original machine. The sludge entered these compartments through ports in the vertical shaft, which remained open until the time for the discharge of the dried cake. The water was forced out of the sludge and through vertical slotted plates, which had tapered openings 0.6 by 10 mm. in size. These thin steel plates were supported by heavier cast-iron frames, in which there were large openings for the passage of the water. Each plate was provided with a scraper to prevent clogging. At the end of a definite period of time, the inlet valves to the six compartments were closed; one side of each compartment automatically opened, and the dried cake was thrown by centrifugal force against the outer housing where it broke up and fell through the bottom of the machine. The operation of the centrifuge was controlled automatically by oil under pressure. The central control device consisted of a revolving disc, which

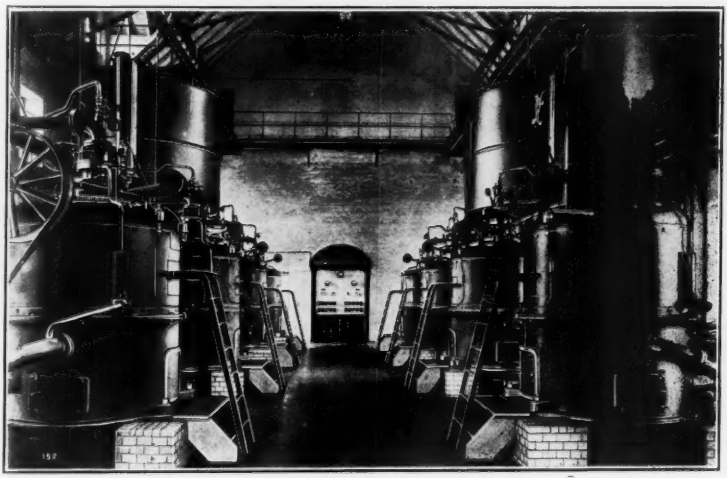


FIG. 3.—Schaefer-ter-Meer Centrifuges at Frankfort-on-the-Main.

actuated a series of cams, and introduced the oil under pressure to the various parts of the machine.

The first centrifuge installation for dewatering sewage sludge was at Harburg, where two machines were installed in 1907. Shortly after this, four centrifuges were erected at Hanover and six at Frankfort-on-the-Main. Later one machine was installed at the sewage works at Bielefeld, and one at Moscow. The installation at Frankfort is shown in Figure 3.

In 1914 many changes and improvements were made to the centrifuge. The six-compartment drum was replaced by a cylindrical drum, which was rotated by means of a belt at 1320 revolutions per minute. The wet sludge was fed into the bottom of this drum through a vertical feed pipe, in which there was an inlet valve controlled automatically by oil pressure. When the valve was opened, the sludge flowed into the centrifuge, and was whirled outward against the rotating, solid drum wall. As more sludge was introduced, a cake about 5 in. thick collected on the inside of the drum. The high pressure, created by the centrifugal force, packed the heavier solids against the drum wall with the liquid nearer the center of the machine. This liquid gradually

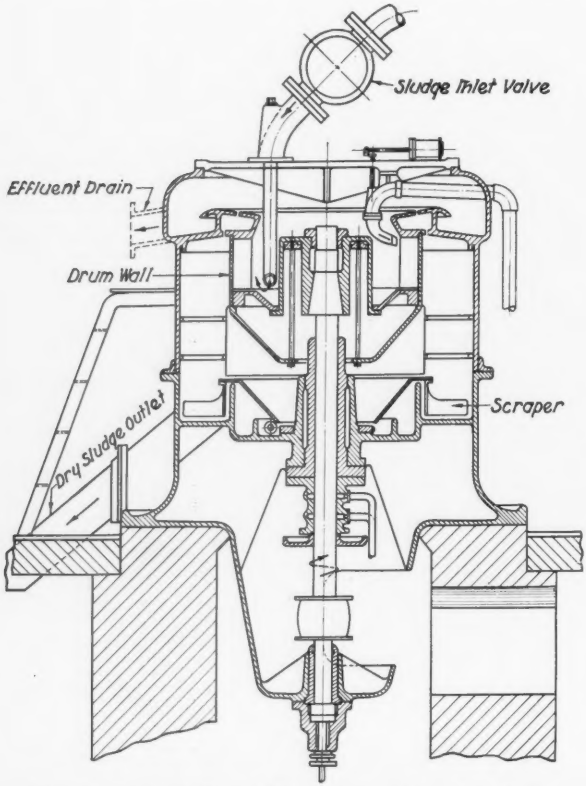



FIG. 4.—Sectional View of First Besco-ter-Meer Centrifuge.

moved upward, and was replaced by the incoming solids until it escaped over the top edge of the drum wall, and flowed into a channel and out of the machine. At the end of a predetermined period, dependent upon the character of the wet sludge, the inlet valve was automatically closed. The dried sludge could then either be discharged or it could be retained in the machine, and centrifuged for an additional period. At the time of the discharge the drum wall was forced downward by oil pressure, and the released cake was flung against the outer casing of the machine. The sludge was then moved by means of a series of scrapers to the discharge outlet in the side. The opening and closing of the inlet valve, and the raising and lowering of the drum wall was automatically operated by oil pressure, which was controlled by a series of cams. The power required to operate the machine was approximately 14 kw. A cross-section of this machine is shown in Figure 4. The old Schaefer-ter-Meer machines at Harburg, Frankfort-on-the-Main, Bielefeld, and Hanover were replaced by the improved type.

**Experiments in the United States.**—This machine was first used in the United States in 1920 at Milwaukee. Additional studies were made at Milwaukee in the summer of 1922 with another centrifuge running at 1700 revolutions per minute. The chief difficulty with the dewatering of activated sludge was that it was impossible to get a clear effluent at an economical rate of operation.

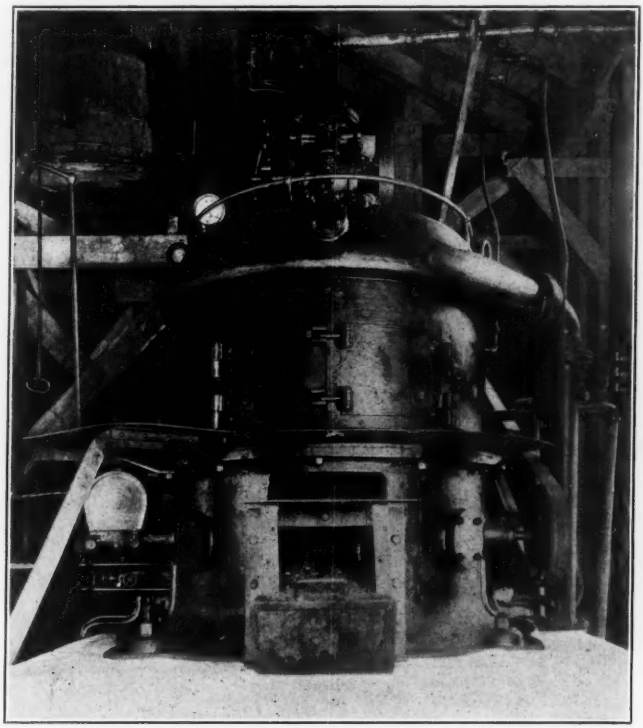


FIG. 5.—Front View of First Centrifuge Tested at Baltimore.

Further improvements were made to the machine in 1923 and 1924, and in September of the latter year an improved centrifuge was sent to Baltimore, at which time extensive experiments were started. Like most other mechanical devices, improvements have been made to the centrifuge from time to time in order to meet the requirements expected of it. A considerable advance has been made over the early efforts of Schaefer.

## Experiments in Baltimore in 1921–1922

Experiments with the centrifuge were begun in Baltimore on December 27, 1921, and continued until March 22, 1922. Figure 5 shows the machine on its foundation at the Baltimore sewage works.

The experiments included the dewatering of undigested, semi-digested and digested sludge. Careful records were kept to determine the capacity of the machine, the moisture in the dried cake, the character of the effluent, and the per cent removal of solids from the sludge. The centrifuge was normally operated at 1320 rev. per min., but it also was run at slower speeds to observe the relation between the speed of the machine and its capacity, the character of the dried cake, and of the effluent. Additional work was done to study the various methods available for clarifying the effluent.

TABLE I

DEWATERING UNDIGESTED SLUDGE

| Inlet Rate | | | Influent Sludge | | | | Cake | | Dry Solids | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Gal. per Min. | Range in Gal. per Min. | No. of Runs | Moisture % | Volatile Matter % | Quantity Centrifuged Gal. | Inlet Period Min. | Weight Lb. | Moisture % | In Influent Lb. | In Cake Lb. | Removal % | Eff. Moisture % |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
| 6.33 | 6 to 6.6 | 5 | 93.3 | 76.2 | 147.1 | 23.32 | 179.0 | 73.6 | 82.1 | 47.3 | 57.6 | 97.0 |
| 11.71 | 10.5 to 13.2 | 6 | 93.4 | 70.4 | 215.9 | 18.21 | 175.3 | 72.7 | 118.3 | 47.8 | 40.4 | 96.1 |
| 19.44 | 18.8 to 20.4 | 5 | 93.5 | 75.1 | 368.4 | 18.95 | 188.6 | 68.8 | 197.5 | 58.8 | 29.8 | 95.2 |

TABLE II

DEWATERING SEMI-DIGESTED SLUDGE

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.40 | 4 to 4.95 | 3 | 91.9 | 62.3 | 115.8 | 26.42 | 204.3 | 69.2 | 78.1 | 63.0 | 80.6 | 96.9 |
| 5.94 | 5.4 to 6.5 | 17 | 93.0 | 63.3 | 115.7 | 19.48 | 194.8 | 72.8 | 67.6 | 53.0 | 78.4 | 97.6 |
| 7.12 | 6.9 to 7.3 | 6 | 92.4 | 61.1 | 152.0 | 21.21 | 204.2 | 69.0 | 96.1 | 63.3 | 65.9 | 96.6 |
| 7.98 | 7.8 to 8.3 | 11 | 93.1 | 62.1 | 154.8 | 18.94 | 191.0 | 72.7 | 88.3 | 52.2 | 59.2 | 97.2 |
| 9.12 | 8.9 to 9.35 | 3 | 93.2 | 61.1 | 171.3 | 18.81 | 199.3 | 70.5 | 97.1 | 58.7 | 60.5 | 96.4 |
| 12.7 | 10.2 to 15.9 | 4 | 91.6 | 62.0 | 119.3 | 9.69 | 170.0 | 72.5 | 83.0 | 46.8 | 56.4 | 96.5 |

TABLE III

DEWATERING DIGESTED SLUDGE

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6.0 | 6.1 | 1 | 94.9 | 56.0 | 147.6 | 25.42 | 184 | 72.4 | 62.6 | 50.8 | 81.2 | 98.5 |
| 8.5 | 8.5 | 1 | 93.3 | 56.0 | 127.5 | 15.00 | 189 | 70.5 | 71.3 | 55.8 | 78.2 | 97.8 |
| 9.75 | 9.75 | 1 | 94.8 | 56.0 | 184.5 | 18.92 | 195 | 73.6 | 79.0 | 51.6 | 65.3 | 98.0 |

TABLE IV

DEWATERING SEMI-DIGESTED SLUDGE WITH DRAINAGE RING IN CENTRIFUGE

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13.9 | | 6 | 92.7 | 66.5 | 158.0 | 11.38 | 200.5 | 71.7 | 95.7 | 57.0 | 59.6 | 96.7 |
| 20.9 | | 3 | 91.8 | 65.1 | 122.5 | 5.86 | 201.0 | 70.0 | 83.1 | 60.3 | 72.6 | 96.1 |

The results obtained with undigested sludge are given in Table I. It is apparent from these figures that as the inlet rate increases the per cent

removal of solids decreases. Table II gives the results with semi-digested sludge. Here again the per cent removal of solids varied inversely as the inlet rate. The results indicate that semi-digested sludge can be dewatered much more readily than undigested sludge. Only a very limited amount of work was done on the dewatering of digested sludge. Three runs in all were made as indicated in Table III. The results show that digested sludge can be more easily dewatered than either undigested or semi-digested material.

The effluent contained from 2 to 5 per cent solids, and its biochemical oxygen demand varied from 1102 to 7328 parts per million. A study was made to find some method of clarifying it. Both plain sedimentation and chemical precipitation were tried. Considerable separation of the solids from the liquid was obtained by the former process, but unsatisfactory results were obtained by precipitation with various amounts of lime and ferrous sulphate, aluminum sulphate and sodium hydroxide. Some of the effluent was collected and again centrifuged, but the results were not conclusive.

Shortly before the experiments were concluded the capacity of the centrifuge was materially increased by making a minor alteration. A slotted metal ring, called a drainage ring, beneath which there were 24 $^3/_8$-in. holes, was installed in the bottom of the chamber in which the sludge was introduced. As the sludge entered the revolving drum, it was packed against this ring, and the water was forced through the slots and then through the holes to the effluent discharge pipe. Nine runs were made on semi-digested sludge using this drainage ring. The results are included in Table IV. The use of the drainage ring produced considerably better results than when the centrifuge was operated without it. Unfortunately it was impossible to continue the work with the drainage ring equipment in order to check the data obtained.

These preliminary tests indicated that the centrifuge was simple in operation, that the automatic control devices worked satisfactorily, and that it would stand hard use because of its sturdy construction. It was believed that if centrifuges could be made having inlet rates equal to those given in Table IV, the cost of dewatering would be almost as low as the cost of air-drying sludge.

### Experiments in Baltimore in 1924–1925

A study of the tests made in 1922 of the results indicated that additional work should be done to obtain more definite and conclusive information. Several important improvements and changes were made to the centrifuge by the manufacturers in 1923. During the latter part of 1924 one of these machines was shipped to Baltimore, and additional work was started.

**Description of the Centrifuge.**—Except for a number of improvements, the remodeled centrifuge was essentially the same as the machine previously described, as illustrated in Figure 4. The new machine is shown in Figures 6 and 7. A vertical section through the inlet valves and a por-

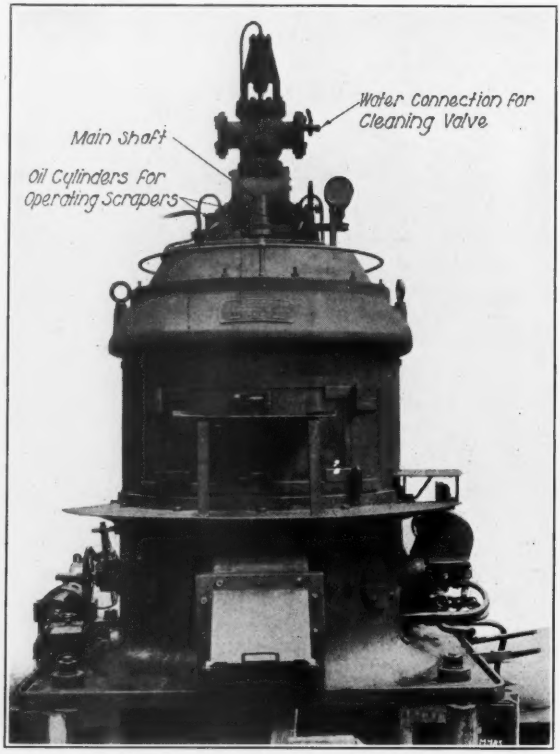



FIG. 6.—Front View of Remodeled Centrifuge.

tion of the drum is given in Figure 8. The sludge enters the centrifuge through inlet valves Nos. 1 and 2, and passes into a drum, which is fixed to a vertical shaft, and revolves at a speed of 1200 rev. per minute. This drum has an internal diameter of 35.43 in. The solids of the incoming sludge are forced against the drum wall, and the liquid flows upward into an upper drum of the same internal diameter as the lower one. This upper drum contains a series of horizontal, perforated plates, placed in parallel tiers one above the other, through which the liquid must pass.

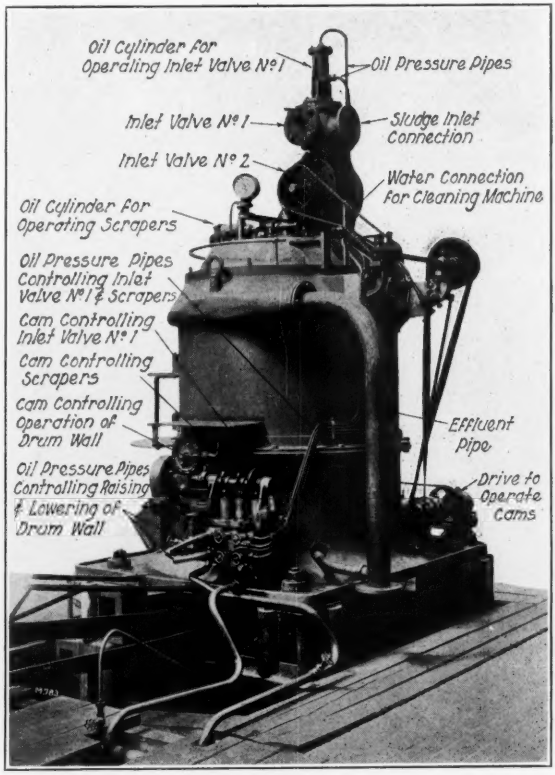

Oil Cylinder for Operating Inlet Valve No 1
Oil Pressure Pipes
Inlet Valve No 1
Sludge Inlet Connection
Inlet Valve No 2
Water Connection for Cleaning Machine
Oil Cylinder for Operating Scrapers
Oil Pressure Pipes Controlling Inlet Valve No 1 & Scrapers
Cam Controlling Inlet Valve No 1
Cam Controlling Scrapers
Cam Controlling Operation of Drum Wall
Effluent Pipe
Oil Pressure Pipes Controlling Raising & Lowering of Drum Wall
Drive to Operate Cams

FIG. 7.—Side View of Remodeled Centrifuge.

These plates are circular with the outer edges attached to the drum wall. Before the liquid, which has separated from the sludge, leaves the centrifuge it flows through two narrow passage-ways, or slots called drainage rings, in the upper drum. These slots consist of a continuous opening around the top of the drum. Each slot is almost completely filled with a broad rubber band, or ring, which permits the passage of water but holds back the solids.

The operation of the centrifuge, though continuous, is made up of three steps, the time of which can be controlled. During the first, called the inlet period, the wet sludge enters the machine, the solids pack against the drum wall, and the effluent passes over the top of the upper drum wall. During the second step, called the post-centrifuge period, wet sludge is not admitted but the dewatering process continues. The length of the first

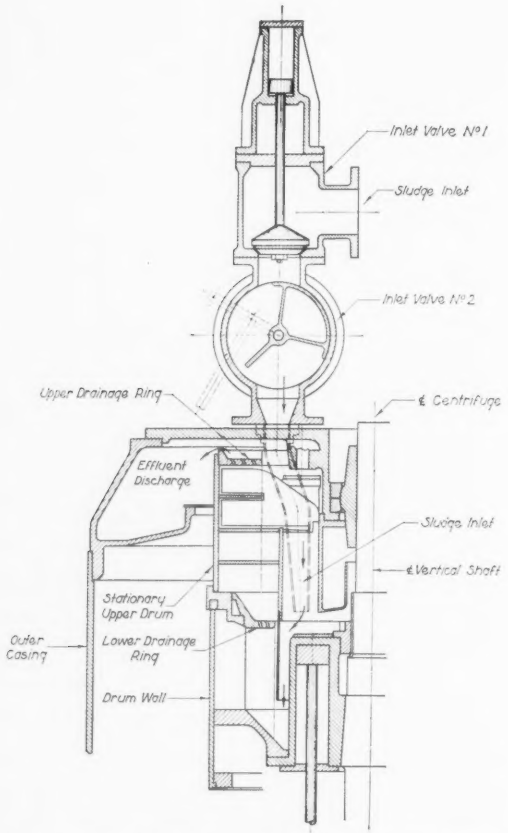



FIG. 8.—Vertical Section through Inlet Valves and Drum of Remodeled Centrifuge.

period usually depends upon the moisture of the sludge. The post-centrifuge period can be dispensed with if a dry cake has been formed during the inlet period. During the third step, known as the discharge period, the dried cake is discharged from the machine. The cake collects in both drums, but the lower one contains by far the larger portion of the solids. The cake is scraped from the upper to the lower drum by means of two scoops, which are actuated by oil pressure. These scoops are placed between the perforated plates in the upper drum, and function at the end of the post-centrifuge period. Immediately after this operation the lower drum wall is forced downward for a few seconds, and the cake is expelled.

The drum wall, after remaining in its lowered position for a few seconds, is raised and closed by oil pressure. Inlet valve No. 1 opens and the cycle of operation is repeated. The cake is then forced automatically to the sludge outlet in the side of the machine. During all three of the above periods, the drum continues to revolve at its rated speed.

The operation of the inlet valve, the scrapers, and the drum wall is controlled by oil under a pressure of 15 atmospheres. The flow of oil is regulated by valves operated by three cams shown in Figure 7. These cams are on one shaft, and are run by a motor through two reduction gears and a chain drive. The entire machine is controlled by these three cams, which function automatically. The two drums are secured to one vertical shaft. The main shaft projects below the base of the machine, and is provided with a pulley for a belt drive.

Once the centrifuge is started, the whole operating process is automatic. With the machine tested, however, it was necessary to open the discharge port after each period of centrifuging to permit the discharge of cake. This operating feature can be dispensed with, as machines can be provided with an open bottom discharge. The cake would thus fall from the machine into a car, storage bin, or other container after each dewatering period.

**Character of Sewage Sludge.**—The Baltimore sewage is collected in a system of separate sewers, and flows through an outfall six miles long to the sewage treatment works. The sewage contains very little industrial wastes. It is screened at the treatment works through coarse-bar screens with $^7/_8$-in. clear openings. It then flows through two sedimentation tanks, each of which has a capacity of 3,800,000 gallons, providing an average detention period of 3 hours. These tanks are unwatered about once a week, and the sludge is pumped to 51 separate digestion tanks, where it decomposes and digests so that it can be readily dewatered. This material is in various states of decomposition, depending partly upon the length of storage, but more particularly upon the temperature and the degree of inoculation with well-digested sludge.

It is difficult to determine exactly the extent to which a sludge has undergone decomposition. Perhaps the best method is to study the decrease in volatile matter. At the Baltimore works sludge which has a volatile content below 53 per cent is considered well-digested, that between 58 and 65 per cent is semi-digested, and that over 70 per cent is undigested.

**Flow of Sludge to Centrifuge.**—The sludge to be dewatered was pumped into a large, open concrete tank 38 ft. in diameter, 24$^1/_2$ ft. deep at the center, and with a total capacity of 154,140 gallons. The suction side of a 4-in. motor-driven centrifugal pump was connected to an 8-in. pipe, which entered the bottom of this tank. The 4-in. discharge pipe from the pump connected with a small, elevated storage tank in a tem-

porary wooden building. This pipe also had a discharge back into the concrete tank so that when the elevated tank became full the excess sludge could be diverted into the concrete tank without stopping the pump. This building also contained the centrifuge, oil accumulator, oil pressure pump, oil reservoir, and electric motors for operating the centrifuge.

As the sludge was pumped into the elevated tank, it passed through a screen with $^3/_8$-in. openings to remove any large material which might clog the working parts of the centrifuge. The tank also contained a stirring device to give the sludge a uniform consistency. This tank was 3 ft. $10^1/_2$ in. in diameter, with a depth of 4 ft., and a total capacity of 352 gallons.

## Preliminary Experiments and Results

The centrifuge was first put in service on October 30, 1924. Several days were required to become familiar with its operation. It was soon learned that the cycle of operation had to be lengthened with a sludge containing a high moisture content. Under normal conditions the centrifuge was adjusted so that it would not discharge its dewatered cake until it was practically full. In order to reduce this time, sludge with a high moisture was inletted at a much higher rate. These preliminary experiments indicated the range in capacity of the machine, the quantity and character of dried sludge produced, and the facility and ease of operation under normal conditions. Although a record of the results was made, they are not shown as more complete data of subsequent experiments are given.

TABLE V

SLUDGE DEWATERED AT INLET RATES FROM 20.7 TO 42.2 GAL. PER MINUTE

| Inlet Rate Gals. per Min. | Influent Sludge | | | | Water Added to Influent Sludge Gals. | Inlet Period Min. | Post Centrifuge Period Min. | Cake | | Dry Solids | | | Effluent | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Runs | Moisture % | Volatile Matter % | Quantity Centrifuged Gals. | | | | Wt. Lb. | Moisture % | In Influent Lb. | In Cake Lb. | Removal % | Moisture % | B.O.D. P.P.M. |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) |
| 20.7 | 14 | 92.1 | 69.3 | 207.1 | ... | 10.1 | 4.46 | 392 | 70.9 | 136.3 | 87.6 | 64.4 | 97.1 | 6600 |
| 25.8 | 15 | 93.1 | 68.1 | 235.2 | ... | 9.1 | 3.58 | 293 | 70.7 | 128.1 | 86.1 | 66.6 | 97.1 | 8300 |
| 24.2 | 31 | 92.7 | 67.4 | 186.0 | 132.3 | 7.7 | 2.66 | 292 | 71.5 | 109.9 | 83.4 | 76.6 | 98.0 | 5700 |
| 31.0 | 22 | 91.6 | 67.6 | 167.7 | ... | 5.41 | 3.38 | 316 | 73.6 | 118.1 | 83.0 | 70.7 | 96.5 | 9400 |
| 30.0 | 17 | 94.5 | 68.8 | 277.0 | 138.5 | 9.24 | 2.63 | 278 | 74.1 | 125.3 | 71.6 | 58.2 | 98.8 | 6400 |
| 34.4 | 15 | 94.0 | 72.0 | 283.4 | ... | 8.23 | 4.35 | 296 | 73.1 | 140.4 | 79.5 | 56.8 | 97.9 | 5800 |
| 38.4 | 12 | 94.8 | 72.5 | 305.5 | ... | 7.96 | 3.33 | 307 | 74.8 | 128.8 | 77.3 | 60.3 | 98.4 | 6300 |
| 42.2 | 15 | 93.5 | 69.8 | 252.5 | ... | 5.98 | 3.57 | 312 | 71.1 | 132.4 | 89.0 | 67.1 | 98.0 | 7600 |

After some time was spent on the preliminary work, the centrifuge was operated for several weeks at inlet rates varying from 20.7 to 42.2 gal. per minute. It was thought that the results would show to what extent, if any, a change in the inlet rate would have upon the moisture in the dried cake, the per cent removal of dry solids, and the biochemical oxygen demand of the liquid separated from the sludge. There were

reasons for believing that the addition of clear water to the sludge after it had entered inlet valve No. 1 would increase the removal of dry solids, and considerable work was done to see what the effect would be.

The results of 141 runs at various inlet rates are summarized in Table V.

A "Run" is the period of time between successive openings of the inlet valve, or one complete cycle of operation. Sludge flows into the machine during the "Inlet Period." The "Post Centrifuge Period" is the time between the closing of the inlet valve and the dropping of the drum wall for the discharge of dried cake.

One 500-cc. sample of wet sludge was obtained from the elevated storage tank during each run. Analyses were made for moisture content and percentage of volatile matter in the dry solids. The quantity of sludge centrifuged was obtained by direct measurements in the storage tank. The dried sludge was discharged from the centrifuge into wheelbarrows, and weighed on a platform scale. This sludge was then dumped on a wooden platform where it was thoroughly mixed and quartered in order to obtain a representative sample. Each sample before drying weighed approximately 100 grams. "Standard Methods for the Examination of Water and Sewage," dated 1923, was followed in making all chemical analyses. The biochemical oxygen demand of the effluent was determined after incubation for 5 days at 20° C. In most cases the effluents from a number of runs were composited and the biochemical oxygen demand was determined. The per cent removal of solids from the sludge was computed by determining the weights of the dry solids in the cake and in the influent sludge. The weight of the former divided by the weight of the latter gave the per cent removal.

The moisture content of the wet sludge varied from a minimum of 88.9% to a maximum of 96.2% with an average of approximately 93.4%. The volatile matter in the dry solids varied from 62.3 to 73.3%, and averaged 68.8%.

The results in Table V indicate that the removal of dry solids was greater when the influent sludge was low in volatile matter. In other words, a better and more complete separation of solids from liquid can be obtained from digested than from undigested sludge. The addition of water to the sludge before it entered the centrifuge had no apparent effect upon the results. When the sludge was dewatered at a rate of 24.2 gal. per min., and a total of 132.3 gal. of water was added, the removal of dry solids was 76.6% as compared with 66.6% when the inlet rate was 25.8 gal. per min., and no water was added. But when the inlet rate was 30.0 gal. per min. with the addition of 138.5 gal. of water, the average per cent removal of dry solids was 58.2 as compared with 70.7% removal with an inlet rate of 31.0 gal. per min. of sludge without the addition of water.

As the inlet rate was increased from 20.7 to 42.2 gal. per min. through

intervals of about 5 gal., there was little change in the moisture of the cake, the per cent removal of dry solids, and the biochemical oxygen demand of the effluent. The machine operated as effectively at high as at low inlet rates.

TABLE VI

ANALYTICAL DATA OF ENDURANCE TEST WITH CENTRIFUGE

| | | Influent Sludge | | | | | Cake | | Dry Solids | | | Effluent | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date (1925) | Rate, G.P.M. | Moisture % | Volatile Matter % | Quantity Centrifuged Gal. per Run | Inlet Period Minutes | Post Centrifuge Period Minutes | Weight Lb. | Moisture % | In Influent Lb. | In Cake Lb. | Removal of % | Moisture % | 5 Day B. O. D. P.P.M. |
| 2/3 | 31.5 | 95.54 | 69.19 | 299.3 | 9.50 | 3.50 | 315 | 72.01 | 111.5 | 88.2 | 79.1 | 98.12 | .... |
| 3/4 | 41.1 | 94.39 | ... | 272.7 | 6.63 | 3.50 | 303 | 72.01 | 127.9 | 84.9 | 67.6 | 98.28 | 5,800 |
| 3/5 | 40.0 | 94.70 | 69.14 | 246.0 | 6.15 | 3.70 | 305 | 73.51 | 108.9 | 80.8 | 74.2 | 98.29 | 6,700 |
| 3/6 | 40.0 | 94.11 | 68.39 | 246.0 | 6.15 | 3.00 | 342 | 72.30 | 121.0 | 94.7 | 78.3 | 98.10 | .... |
| 3/9 | 40.0 | 91.95 | ... | 246.0 | 6.15 | 3.00 | 339 | 76.65 | 165.4 | 79.2 | 47.9 | 96.99 | 8,000 |
| 3/10 | 40.0 | 94.06 | 70.79 | 252.0 | 6.30 | 3.50 | 315 | 73.49 | 125.0 | 83.7 | 66.8 | 97.74 | .... |
| 3/11 | 36.3 | 94.07 | ... | 275.9 | 7.60 | 3.25 | 335 | 73.40 | 136.6 | 89.1 | 65.2 | 97.95 | 5,300 |
| 3/12 | 36.3 | 95.05 | 69.77 | 275.9 | 7.60 | 3.25 | 275 | 76.76 | 114.0 | 63.9 | 56.1 | 98.10 | 7,900 |
| 3/17 | 49.5 | 94.67 | ... | 306.9 | 6.20 | 3.10 | 325 | 72.92 | 136.6 | 88.0 | 64.4 | 98.16 | 4,700 |
| 3/30 | 43.0 | 92.06 | 67.76 | 279.0 | 6.46 | 3.10 | 332 | 70.18 | 184.2 | 99.1 | 53.8 | 96.08 | .... |
| 3/31 | 37.7 | 94.08 | 68.19 | 248.8 | 6.60 | 3.50 | 380 | 72.03 | 123.0 | 106.3 | 86.5 | 96.97 | 12,400 |
| 4/1 | 44.0 | 93.66 | 70.35 | 297.9 | 6.60 | 3.50 | 352 | 70.76 | 157.6 | 102.6 | 66.4 | 96.68 | 13,100 |
| 4/2 | 27.6 | 93.83 | 70.51 | 322.9 | 11.73 | 3.50 | 349 | 70.38 | 166.9 | 103.3 | 62.3 | 97.07 | 11,500 |
| 4/3 | 36.6 | 94.09 | ... | 375.6 | 10.27 | 3.90 | 365 | 70.70 | 185.3 | 107.1 | 57.8 | 97.10 | 10,200 |
| 4/11 | 40.5 | 93.52 | 64.13 | 303.8 | 7.50 | 3.90 | 327 | 66.61 | 164.5 | 110.9 | 67.5 | 97.30 | 6,000 |
| 4/13 | 45.9 | 93.74 | 63.84 | 346.9 | 7.55 | 3.85 | 351 | 68.31 | 180.6 | 111.3 | 61.9 | 97.42 | 8,200 |
| 4/14 | 44.2 | 94.46 | 65.58 | 333.7 | 7.55 | 3.83 | 340 | 70.70 | 154.5 | 99.7 | 64.4 | 97.73 | 8,600 |
| 4/15 | 42.8 | 94.58 | 66.12 | 322.8 | 7.55 | 3.90 | 327 | 70.43 | 146.3 | 97.0 | 66.1 | 97.83 | 8,200 |
| 4/16 | 46.0 | 95.15 | 67.76 | 345.0 | 7.50 | 3.90 | 304 | 70.84 | 139.7 | 88.6 | 63.4 | 97.98 | 8,600 |
| 4/21 | 39.1 | 93.21 | 65.08 | 305.0 | 7.50 | 3.90 | 359 | 69.11 | 171.3 | 110.8 | 65.2 | 97.01 | 9,200 |
| 4/22 | 41.0 | 93.40 | 68.78 | 307.2 | 7.50 | 3.92 | 363 | 68.66 | 169.4 | 113.9 | 67.7 | 96.76 | 10,600 |
| 4/23 | 43.2 | 94.28 | 71.60 | 332.5 | 7.53 | 3.92 | 372 | 72.51 | 156.4 | 102.3 | 65.5 | 96.96 | 12,400 |
| 4/24 | 35.9 | 94.02 | 69.23 | 270.8 | 7.55 | 3.90 | 319 | 72.01 | 135.0 | 89.4 | 66.3 | 97.42 | 14,600 |
| 4/27 | 36.8 | 92.82 | 70.64 | 278.7 | 7.53 | 3.90 | 323 | 69.39 | 164.8 | 98.7 | 60.1 | 96.50 | 13,200 |
| 4/28 | 41.4 | 94.26 | 70.97 | 310.7 | 7.50 | 3.90 | 320 | 73.13 | 149.0 | 86.1 | 58.2 | 97.10 | 7,200 |
| 4/29 | 40.1 | 94.30 | 69.59 | 302.6 | 7.56 | 3.90 | 311 | 69.72 | 143.9 | 94.1 | 65.6 | 97.17 | 8,600 |
| 4/30 | 42.8 | 94.67 | 70.27 | 325.0 | 7.55 | 3.93 | 349 | 71.56 | 144.0 | 99.5 | 69.0 | 97.38 | 8,600 |
| 5/1 | 43.3 | 94.78 | 70.79 | 326.7 | 7.55 | 3.92 | 310 | 70.86 | 142.2 | 90.5 | 63.6 | 97.40 | 9,000 |
| Avg. | 40.2 | 94.05 | 68.63 | 298.4 | 7.48 | 3.64 | 332 | 71.46 | 147.3 | 95.1 | 65.4 | 97.41 | 9,100 |

## Continuous Operating Test

After the above tests were completed, the centrifuge was operated for several weeks on as close to a practicable working basis as possible. Each day the machine was started in the morning, and was kept in continuous operation for about 6 or 7 hours. Careful records were kept of the power consumption, and experiments were made on the treatment of the effluent.

The analytical data obtained during the continuous operation test are shown in Table VI. This test lasted for 28 days, during which time a total of 288,691 gal. of sludge were dewatered and 324,819 lb. of dried cake were produced. An average of 40.1 gal. of sludge was dewatered a minute. The average moisture in the wet sludge was 93.9%, as com-

pared with 91.21% moisture in the sludge put on the drying beds at Baltimore during 1924.

The dewatered sludge contained 71.1% moisture, and the sludge removed during 1924 from the sludge beds 71.4%; so the two are comparable as far as their moistures are concerned. Sludge of the above consistency is sufficiently dry to shovel, but not to handle with forks. The sludge was not well digested since the volatile material averaged 68.9 per cent. Each batch was centrifuged on an average of 11.25 minutes. The inlet period lasted 7.58 minutes, and the post-centrifuge period 3.67 minutes. The average total removal of dry solids amounted to 65.1 per cent. The

TABLE VII

DATA SHOWING OUTPUT OF CENTRIFUGE AND POWER USED

| Date | Time Centrifuge was Operated Hrs. | Estimated No. Runs Based on an 8-Hr. Day | No. of Runs | Current Used: 25 H.P. Motor Operating Centrifuge K. W. H. | 25 H.P. Motor on Oil Pump K. W. H. | 3 H.P. Motor on Control System of Centrifuge* K. W. H. | Total K. W. H. | Quantity of Sludge De-watered Gal | Quantity of Cake Lb. |
|---|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| 2/3/25 | 6 hrs. 50 min. | 33.9 | 29 | ... | ... | ... | ... | 8,680 | 9,135 |
| 3/4/25 | 6 hrs. 30 min. | 40.6 | 33 | 190 | 60 | 18 | 268 | 8,993 | 10,032 |
| 3/5/25 | 7 hrs. 30 min. | 35.2 | 33 | 90 | 60 | 20 | 170 | 8,118 | 10,065 |
| 3/6/25 | 7 hrs. 30 min. | 42.6 | 40 | 240 | 100 | 7 | 347 | 9,840 | 13,680 |
| 3/9/25 | 7 hrs. 30 min. | 43.7 | 41 | 130 | 60 | 7 | 197 | 10,086 | 13,899 |
| 3/10/25 | 7 hrs. 0 min. | 42.3 | 37 | 160 | 60 | 14 | 234 | 9,324 | 11,655 |
| 3/11/25 | 7 hrs. 0 min. | 42.3 | 37 | 160 | 70 | 14 | 244 | 10,208 | 12,395 |
| 3/12/25 | 6 hrs. 0 min. | 37.3 | 28 | 120 | 50 | 9 | 179 | 7,725 | 7,700 |
| 3/17/25 | 7 hrs. 30 min. | 35.2 | 33 | 140 | 60 | 16 | 216 | 10,128 | 10,725 |
| 3/30/25 | 5 hrs. 10 min. | 29.4 | 19 | 120 | 60 | 7 | 187 | 5,280 | 6,346 |
| 3/31/25 | 6 hrs. 37 min. | 50.8 | 42 | 190 | 60 | 14 | 264 | 10,450 | 15,960 |
| 4/1/25 | 5 hrs. 45 min. | 50.1 | 36 | 200 | 80 | 16 | 296 | 10,454 | 12,528 |
| 4/2/25 | 7 hrs. 45 min. | 35.1 | 34 | 130 | 60 | 11 | 201 | 10,992 | 11,866 |
| 4/3/25 | 7 hrs. 05 min. | 36.3 | 32 | 180 | 70 | 11 | 261 | 12,019 | 11,712 |
| 4/11/25 | 7 hrs. 30 min. | 37.3 | 35 | 140 | 70 | 9 | 219 | 10,633 | 11,445 |
| 4/13/25 | 6 hrs. 10 min. | 44.1 | 34 | 160 | 70 | 14 | 244 | 11,781 | 11,968 |
| 4/14/25 | 7 hrs. 45 min. | 43.4 | 42 | 180 | 80 | 11 | 271 | 14,015 | 14,280 |
| 4/15/25 | 6 hrs. 30 min. | 33.4 | 28 | 130 | 70 | 11 | 211 | 9,038 | 9,156 |
| 4/16/25 | 5 hrs. 30 min. | 34.9 | 24 | 140 | 70 | 7 | 217 | 8,299 | 7,296 |
| 4/21/25 | 7 hrs. 05 min. | 47.7 | 42 | 190 | 90 | 16 | 296 | 12,319 | 14,784 |
| 4/22/25 | 6 hrs. 25 min. | 34.9 | 28 | 140 | 70 | 14 | 224 | 8,602 | 10,164 |
| 4/23/25 | 6 hrs. 0 min. | 34.7 | 26 | 130 | 70 | 11 | 211 | 8,458 | 9,672 |
| 4/24/25 | 6 hrs. 30 min. | 38.1 | 31 | 150 | 70 | 14 | 234 | 8,392 | 9,920 |
| 4/27/25 | 5 hrs. 30 min. | 37.8 | 26 | 130 | 60 | 7 | 197 | 7,202 | 8,424 |
| 4/28/25 | 7 hrs. 0 min. | 42.3 | 37 | 170 | 70 | 14 | 254 | 11,492 | 11,877 |
| 4/29/25 | 6 hrs. 30 min. | 45.5 | 37 | 170 | 70 | 11 | 251 | 11,196 | 11,507 |
| 4/30/25 | 7 hrs. 30 min. | 42.6 | 40 | 180 | 80 | 14 | 274 | 12,928 | 13,920 |
| 5/1/25 | 7 hrs. 30 min. | 39.4 | 37 | 180 | 70 | 11 | 261 | 12,084 | 11,507 |
| Average | 6 hrs. 45 min. | 39.7 | 33.6 | 157 | 69 | 12.1 | 238 | 9,955 | 11,201 |

* Current used by 3-h.p. motor is estimated.

effluent contained an average of 97.3 per cent water with a biochemical oxygen demand of 9100 p. p. m.

The operating data are given in Table VII. Watt-hour meters were employed to determine the amount of current consumed, except for the 3-h.p. motor, which operated the control system of the centrifuge. The current consumption of this motor was therefore estimated. The results show that a total of 238 kw-hr. of current would be used by the machine and its supplementary equipment during an 8-hr. day, and in this time 39.7 runs would be made.

**Effluent from the Centrifuge.**—The effluent from the centrifuge contained several per cent of solids. At the Baltimore sewage works this liquid could not be discharged into the adjacent watercourse, and for that reason considerable study was devoted to methods of treatment. Of these the following seemed to be the most worthy of consideration:

1. Treatment on trickling filters
2. Dilution of effluent with untreated sewage
3. Chemical precipitation.

Unfortunately there was not sufficient time to conduct experiments on the treatment of the effluent on trickling filters, and there is some question as to whether satisfactory results would have been obtained.

Consideration was given to the possibility of pumping the centrifuge effluent into the raw sewage flowing to the sewage works. In order to determine what effect the effluent would have on the untreated sewage, the two were mixed in the laboratory in various proportions, and the biochemical oxygen demand of the mixture was determined, as indicated in Table VIII. Nineteen different samples of untreated sewage and centrifuge effluent were selected. The B. O. D. was determined by the dilution method after an incubation period of 5 days at room temperature. The untreated sewage was filtered through absorbent cotton in order to remove any large suspended matter. The average B. O. D. of the 19 samples of sewage was 184 p. p. m. and of the centrifuge effluent 10,000 parts per million. The B. O. D. of mixtures of the two liquids varied from 180 p. p. m., when the ratio of centrifuge effluent to sewage was 1 to 2000, to 240 p. p. m. when the ratio was 1 to 250. The data in this table are represented in Figure 9 as a hyperbolic curve. Based on the present sewage flow, which is about 55 million gallons per day, it is estimated that if all the sludge at Baltimore were to be dewatered by centrifuges the ratio of the total quantity of centrifuge effluent to the total sewage flow would be about 1 to 1250. If the two were mixed in this proportion, the average B. O. D. of the sewage would be raised from 184 to 192 p. p. m., an increase of 4.3 per cent. This ratio would vary considerably if the centrifuges were operated for only a portion of the day and means were not provided for storing the effluent so that it could be added to the sewage throughout

the 24 hours. Figure 9 shows the calculated and determined B. O. D. of mixtures of sewage and centrifuge effluent in various proportions. The agreement between the two curves is close, and within the range of error of the B. O. D. determination.

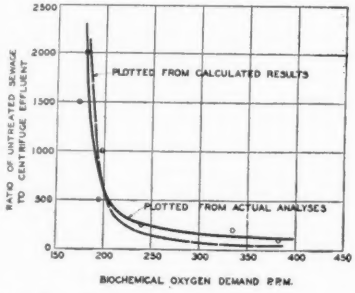

RATIO OF UNTREATED SEWAGE TO CENTRIFUGE EFFLUENT
PLOTTED FROM CALCULATED RESULTS
PLOTTED FROM ACTUAL ANALYSES
BIOCHEMICAL OXYGEN DEMAND P.P.M.

FIG. 9.—Biochemical Oxygen Demand of Diluted Centrifuge Effluent.

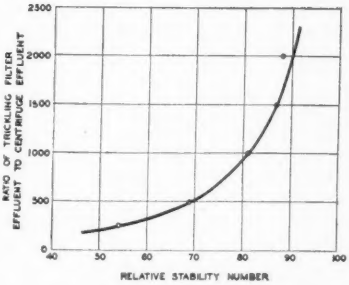



FIG. 10.—Relative Stability of Diluted Centrifuge Effluent.

TABLE VIII

BIOCHEMICAL OXYGEN DEMAND OF MIXTURES OF CENTRIFUGE EFFLUENT AND SEWAGE

Results in Parts per Million, 5-Day B. O. D. at Room Temperature

| Sample No. | Sewage* | Ratio of Centrifuge Effluent to Sewage | | | | | Centrifuge Effluent |
|---|---|---|---|---|---|---|---|
| | | 1/2000 | 1/1500 | 1/1000 | 1/500 | 1/250 | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| 1 | 310 | 350 | ... | 330 | ... | ... | .... |
| 2 | 250 | 210 | ... | 180 | ... | ... | 12,400 |
| 3 | 265 | 230 | 240 | 285 | 230 | 210 | 13,100 |
| 4 | 265 | 215 | 325 | 255 | 300 | 320 | 11,500 |
| 5 | 300 | 215 | 185 | 400 | 280 | 535 | 10,200 |
| 6 | 78 | 93 | 78 | 88 | 118 | 128 | 6,000 |
| 7 | 168 | 130 | 175 | 160 | 173 | 260 | 8,200 |
| 8 | 145 | 175 | 160 | 200 | 180 | 215 | 8,600 |
| 9 | 198 | ... | ... | 100 | 95 | 150 | 8,200 |
| 10 | 150 | 180 | 168 | 220 | 180 | ... | 8,600 |
| 11 | 135 | 175 | 180 | 175 | 195 | 230 | 9,200 |
| 12 | 110 | 125 | 150 | 146 | 173 | 208 | 10,600 |
| 13 | 198 | 180 | 185 | 180 | 215 | 215 | 12,400 |
| 14 | 175 | 170 | 165 | 205 | 220 | 270 | 14,600 |
| 15 | 190 | 203 | 208 | 225 | 236 | 300 | 13,200 |
| 16 | 140 | 165 | 155 | 195 | 200 | 196 | 7,200 |
| 17 | 100 | 100 | 115 | 110 | 155 | 215 | 8,600 |
| 18 | 130 | 150 | 145 | 153 | 170 | 185 | 8,600 |
| 19 | 185 | 170 | 150 | 150 | 190 | 210 | 9,000 |
| Average | 184 | 180 | 174 | 198 | 195 | 240 | 10,000 |

* Sewage was filtered through absorbent cotton but was otherwise untreated.

Further study was made to learn the effect of diluting the centrifuge effluent with various quantities of effluent from the trickling filters, which are $8^1/_2$ ft. deep, and composed of stone varying in size from 1 to $2^1/_2$ inches. Seventeen samples of filtered sewage, and 17 samples of centrifuge effluent were used. These were mixed in various proportions, and the relative stabilities of the mixtures were determined by the methylene blue test. The average relative stability of the trickling filter effluent was 96. With a mixture containing 250 parts of filtered sewage and 1 part of centrifuge effluent the relative stability averaged 54. The data are shown in graphic form in Figure 10.

**Chemical Precipitation.**—The moisture of the centrifuge effluent, as shown in Table VI, averaged 97.4% for 28 days. This liquid varied from gray to brown in color, and contained large quantities of colloidal matter. It was thought that the solids might be coagulated by some electrolyte. Laboratory experiments were conducted in which small quantities of lime, ferrous sulphate, and alum were added separately to the effluent in 50-cc. nessler tubes. Little success was had with lime; better results were obtained with ferrous sulphate; the most satisfactory results were had with alum. The alum solution was prepared by dissolving 100 lb. of lump alum (commercial grade) in 60 gal. of water.

The effluent was put in one-gallon containers, to which from 0.14 to 0.49 oz. of alum was added. Coagulation caused the lighter solids to rise to the top of the liquid while the remainder settled to the bottom. At the end of 2, 3, 4, and 21 hr. the amount of the separation was noted. Considerably more separation occurred after 21 hr. than after 4 hours. Most of the solids floated to the top of the liquid. The results obtained by using 0.21 oz. of alum per gallon of effluent were about as good as with larger amounts.

In order to check these results on a somewhat larger scale, alum varying in quantities from 0.21 to 0.56 oz. per gal. was added to 10-gal. samples of effluent. The results are tabulated in Table IX. Three groups of tests were made, with observations at the end of 3, 24 and 48 hr. As noted in the tests with the 1 gal. samples, most of the solid material rose to the top of the liquid, although more solids settled to the bottom than in the 1-gal. bottles. Coagulation with 0.21 oz. of alum per gal. was not entirely satisfactory, but the use of 0.28 oz. per gal. produced results practically as good as with larger amounts. Considerably more separation of the colloids was obtained at the end of 24 hr. than at the end of 3 hr., but there was little difference in the extent of coagulation at the end of the 24- and 48-hr. periods.

At the end of the 48-hr. period portions of the clarified effluent from the mid-sections of all of the samples were siphoned off, and their chemical characteristics were determined, as shown in Table X. The quantity of

## Table IX

### Quantities of Solids Coagulated from Centrifuge Effluent with Alum

(10 Gal. of Effluent Used)

| Quantity of Alum Added | Sedimentation Time: Test No. 1 — Solids at Top | | | Test No. 1 — Liquid Mid-Section | | | Test No. 1 — Solids at Bottom | | | Test No. 2 — Solids at Top | | | Test No. 2 — Liquid Mid-Section | | | Test No. 2 — Solids at Bottom | | | Test No. 3 — Solids at Top | | Test No. 3 — Liquid Mid-Section | | Test No. 3 — Solids at Bottom | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oz. per Gal. | 3 Hr. | 24 Hr. | 48 Hr. | 3 Hr. | 24 Hr. | 48 Hr. | 3 Hr. | 24 Hr. | 48 Hr. | 3 Hr. | 24 Hr. | 48 Hr. | 3 Hr. | 24 Hr. | 48 Hr. | 3 Hr. | 24 Hr. | 48 Hr. | 24 Hr. | 48 Hr. | 24 Hr. | 48 Hr. | 24 Hr. | 48 Hr. |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) | (19) | (20) | (21) | (22) | (23) | (24) | (25) |
| 0.21 | | | | | | | | | | | | | | | | | | | 50 | 50 | 32 | 30 | 18 | 20 |
| | | | | | | | | | | U | U | U | U | U | U | U | U | U | | | D | D | | |
| 0.28 | 45 | 40 | 44 | 37 | 50 | 46 | 18 | 10 | 10 | 50 | 42 | 42 | 15 | 38 | 38 | 35 | 20 | 20 | 52 | 50 | 40 | 42 | 8 | 8 |
| | | | | VD | VD | D | | | | | | | | D | D | | | | | | Y | Y | | |
| 0.35 | 60 | 50 | 48 | 30 | 45 | 44 | 10 | 5 | 8 | 58 | 44 | 45 | 10 | 36 | 37 | 32 | 20 | 18 | 55 | 56 | 37 | 36 | 8 | 8 |
| | | | | VD | D | D | | | | | | | | Y | Y | | | | | | L | L | | |
| 0.42 | 52 | 45 | 45 | 30 | 40 | 43 | 18 | 15 | 12 | 68 | 50 | 50 | 25 | 42 | 42 | 7 | 8 | 8 | 55 | 54 | 37 | 38 | 8 | 8 |
| | | | | VD | L | L | | | | | | | | L | L | | | | | | L | L | | |
| 0.49 | 58 | 50 | 50 | 32 | 42 | 42 | 10 | 8 | 8 | 65 | 50 | 45 | 30 | 45 | 50 | 5 | 5 | 5 | 50 | 50 | 42 | 42 | 8 | 8 |
| | | | | D | L | L | | | | | | | | L | L | | | | | | L | L | | |
| 0.56 | 58 | 50 | 48 | 32 | 40 | 42 | 10 | 10 | 10 | | | | | | | | | | | | | | | |
| | | | | L | L | L | | | | | | | | | | | | | | | | | | |

Key:

U—Uneven separation
E—Sharp separation
VD—Very dark
D—Dark
Y—Yellow
L—Light
T—Solids at top
M—Liquids in mid-section
B—Solids at bottom

suspended solids was lowest in that sample to which 0.42 oz. of alum had been added. The turbidity of the liquids was determined by the turbidimetric method as outlined in the "Standard Methods for the Examination of Water and Sewage," and is shown in column 3. The larger the amount of alum added the less was the turbidity. With 0.49 oz. of alum per gallon of effluent the vanishing depth of the image of a candle was 69 cm. whereas with the addition of 0.28 oz. per gallon the vanishing depth was 23 cm. By increasing the amount of alum from 0.28 to 0.56 oz. per gallon the biochemical oxygen demand was reduced from 2815 to 1295 parts per million.

TABLE X

LIQUID FROM ALUM-TREATED CENTRIFUGE EFFLUENT

| Quantity of Alum Added Ounces per Gal. | Suspended Solids P. P. M. | Vanishing Depth of Image of Candle Cm. | Biochemical Oxygen Demand 20° C. for 5 Days P. P. M. |
|---|---|---|---|
| (1) | (2) | (3) | (4) |
| 0.21 | No perceptible coagulation of colloids | | |
| 0.28 | 207 | 23 | 2815 |
| 0.35 | 180 | 50 | 2100 |
| 0.42 | 143 | 59 | 1810 |
| 0.49 | 147 | 69 | 1715 |
| 0.56 | 147 | .. | 1295 |

The average moisture of the effluent (see Table VI) over a period of 28 days was 97.4 per cent, or the total calculated solid content was 27,200 parts per million. Since most of the solids in the effluent were in a colloidal state, it was impossible to determine the true amount of suspended solids. The liquid which separated out after alum treatment had approximately the same amount of suspended solids as Baltimore sewage, which averaged 262 p. p. m. from 1916 to 1925, inclusive.

As the vanishing depth of the image of a candle when viewed through the settled sewage from the Baltimore works was 23 cm., the centrifuge effluent treated with alum had a lower turbidity except in the case where 0.28 oz. of alum was added. The B. O. D. of the coagulated effluent was considerably higher than that of the untreated sewage, which averaged 147 p. p. m. from 1916 to 1925, inclusive.

**Mechanical Functioning of the Centrifuge.**—The centrifuge was kept under close observation to determine with what degree of reliability its various parts functioned, and to find out the time required to supervise its operation when it was running automatically. At times during its operation the upper and lower bearings gave some trouble, but these difficulties were corrected with no great loss of time. The automatic functioning of the machine, which involved inletting the sludge, centrifuging, post-centrifuging, and discharging the cake, worked satisfactorily and consistently. To operate a centrifuge with the least amount of atten-

tion the sludge to be dewatered should have a uniform moisture content so that the inlet rate need not be changed. This condition can be accomplished by using large storage tanks equipped with stirring mechanism so that the sludge can be agitated and kept at a uniform consistency.

## Estimated Cost of Dewatering Sludge

One point of chief importance with reference to the dewatering of sewage sludge by means of centrifuges is to determine the cost of the process for comparison with costs of other adopted methods of sludge drying. Sludge has been dewatered for a number of years at Baltimore on sludge drying beds. In the following studies the cost of dewatering with centrifuges is compared with the cost of air-drying. The estimates are based on the assumption that the character and quantity of sewage and sludge would be similar to existing conditions in Baltimore. The cost of electric current, labor and materials is based on 1928 costs in Baltimore.

The following data have been used in preparing the estimate:

| | |
|---|---|
| Sewage flow | 55.0 m. g. d. |
| Contributing population | 700,000 |
| Yearly quantity of sludge to dewater | 91,700 cu. yd. |
| Moisture content of sludge | 91.82 per cent |
| Number of working days per year | 300 |
| Time centrifuges are operating per day | 8 hr. |

As indicated by Table VII an average of 9955 gal. of sludge was dewatered in $6^3/_4$ hr. or 1483 gal. per hour. With a yearly quantity of 91,700 cu. yd. of sludge, 7736 gal. would have to be dewatered each hour if the centrifuges were to work 2400 hr. a year. Therefore, 5.22, or six centrifuges, would be required. Five would be in operation continuously during each 8-hr. period, and the sixth would be a spare unit except for a short period each day.

A complete dewatering plant would consist of six centrifuges, each operated by a vertical electric motor, one oil accumulator, and three overhead steel sludge tanks, each 18 ft. in diameter, $12^1/_2$ ft. deep, and with a working capacity of 20,700 gallons. With five centrifuges in operation these three tanks would be sufficiently large to hold a supply for eight hours. Furthermore, there would be provided valves and piping from these tanks to the centrifuges, drain pipes for carrying the effluent from the machines, and a system of conveyors for transporting the dried sludge to a storage pile. All of this equipment would be in a brick building 63 by 46 ft. in plan and 30 ft. high at the eaves. The costs are summarized as follows:

| | |
|---|---|
| Building | $ 32,100.00 |
| 6 centrifuges, including installation at $18,000 each | 108,000.00 |
| Sludge storage tanks | 8,600.00 |
| Cast iron piping and valves | 2,600.00 |

| | |
|---|---|
| Drain piping | 800.00 |
| Belt conveyors | 5,800.00 |
| Electrical wiring, etc | 4,100.00 |
| | $162,000.00 |

The annual interest charge on the above amount at $4\frac{1}{2}$ per cent is $7290, and the total depreciation and maintenance charges at $7\frac{3}{4}$ per cent are $12,555.

In dewatering the sludge with centrifuges two methods of operation may be considered. The first would comprise coagulating the effluent with alum and settling. The second would consist of mixing the untreated centrifuge effluent with trickling filter effluent or allowing the undiluted centrifuge effluent to flow to its ultimate point of disposal. It would not be practicable to dewater the sludge by the first method because approximately 40 per cent of the original 91,700 cu. yd. would be present as a coagulated sludge which would have to be handled and dewatered. It seems apparent that the cost of rehandling and drying this large volume of material would so increase the total cost that it would not be applicable except in a few unusual cases. The cost of dewatering as covered by the second method would be as follows:

| | |
|---|---|
| Cost of labor per year: | |
| 1 Operator | $1500.00 |
| 1 Oiler | 1320.00 |
| 1 Laborer 300 days at $3.60 | 1080.00 |
| | $3900.00 |

An average of 238 kw-hr. of electric current (see Table VII) was used to operate the centrifuge and its auxiliary equipment during a period of $6\frac{3}{4}$ hr., or 1472 kw-hr. on the basis that an equivalent of 5.22 centrifuges would operate for an 8-hr. period. It is estimated that the current required to operate the belt conveyors, and other miscellaneous equipment would be 60 kw-hr. The total current consumed daily would be 1532 kw-hr. or 459,600 kw-hr. a year. The following summarizes the total estimated yearly cost:

| | | |
|---|---|---|
| Fixed cost: | | |
| Interest on investment $162,000 at $4\frac{1}{2}\%$ | $7,290.00 | |
| Depreciation and maintenance $162,000 at $7\frac{3}{4}\%$ | 12,555.00 | $19,845.00 |
| Operating cost: | | |
| Labor | 3,900.00 | |
| Electric current 459,600 kw-hr. at $2\frac{1}{4}¢$ | 10,341.00 | |
| Coal, oil, etc | 459.00 | 14,700.00 |
| Total cost | | $34,545.00 |

As 25,910 cu. yd. of cake would be produced the total estimated cost of dewatering would be $1.33 per cubic yard, with 71% moisture content.

Sludge is usually dewatered in the United States by air-drying on sludge beds. The following data are given on the cost of air-drying sludge at Baltimore for comparison with the estimated cost of centrifuging sludge. The first cost of the sludge drying beds has been assumed to be $20,000 per acre, which is the cost of sludge beds recently built at Baltimore. A labor charge of 45 cents per hour has been used. The following is the cost of air-drying sludge per cubic yard with 71% moisture content:

| | |
|---|---|
| Interest on investment | $0.37 |
| Depreciation and maintenance | 0.38 |
| Putting sludge on beds | 0.05 |
| Removing sludge from beds | 0.50 |
| Total | $1.30 |

These costs are based on the assumption that the sludge will be removed from the beds 3¾ times a year, which is about the average at Baltimore. At those sewage works where the sludge dries more quickly and more can be put on the beds, the cost will be relatively less. From these comparative estimates it is apparent that the cost of dewatering sludge by centrifuges and sludge drying beds is about the same.

## Conclusions

The experiments indicate that sludge similar to that at the Baltimore plant can be dewatered by a continuous, automatic centrifuge at a rate as high as 42.2 gal. per min. At this rate the sludge cake will be sufficiently dry so that it can be easily handled. In the 28-day test an average inlet rate of 40.1 gal. per min. was maintained. At this rate one machine was capable of dewatering 11,800 gal. every 8 hr. with a total current consumption of 295 kilowatt-hours. The removal of dry solids averaged 65.1%, and the moisture of the cake was 71.05%, which is about the same as the average moisture content of the air-dried sludge at Baltimore. When sludge is air-dried, it is possible to keep it on the beds sufficiently long so that its moisture will be 50% or even lower. The centrifuged sludge was not so dry as this, the moisture usually averaging more than 65 per cent.

The average moisture content of the effluent from the centrifuge was 97.3%, and the B. O. D. was 9100 parts per million. It was found possible to reduce the B. O. D. to 2815 p. p. m. by adding 0.28 oz. of alum per gal. of effluent. If alum were used on an extensive scale the cost of dewatering the sludge would be increased about ten to twelve cents a cubic yard. No study was made to determine how readily the coagulated solids in the effluent would dry on an underdrained sand bed.

Additional investigations were made to determine the effect of adding the effluent to untreated and to filtered sewage. The experiments indicate that in the first case the B. O. D. of the untreated sewage would be increased 4.3% if this practice were to be adopted at Baltimore. Nothing was done to determine whether any of the colloidal material in the centrifuge effluent would be removed in a settling tank, or what effect, if any, this material would have upon the operation of trickling filters. In all probability such a study would have a direct bearing on the applicability of centrifuges at some sewage works. When one part of effluent was added to 1250 parts of sewage treated on trickling filters, the relative stability of the latter was reduced from 96 to 84. No information is available to indicate whether or not the diluted effluent would form sludge banks in the body of water into which it would flow.

In comparing the dewatering of sludge by air-drying and by centrifuging, points can be enumerated in favor of each process. The moisture content of sludge dried on sand beds can be reduced considerably below that of the dried cake from centrifuges. Although the centrifuged cake may be wetter there should be no difficulty in handling the material when its moisture content is not over 70 to 72 per cent. When the effluents from sludge beds and centrifuges are compared, it is apparent that the former can be disposed of more easily than the latter. At the Baltimore plant the effluent from the sand beds drains first through a layer of sand about 4 in. thick, and then through graded gravel about 12 in. thick. The effluent is clear and has an average B. O. D. of 365 parts per million. Further experiments should be conducted on the centrifuge effluent to determine the various possibilities of treating it before any final conclusions are reached.

The advantages of using centrifuges as compared with sludge beds are apparent. Sludge can be dewatered with centrifuges during unfavorable weather conditions and at all times of the year. Furthermore, large quantities of sludge are not exposed to the atmosphere; and should the wet sludge be only partially digested, there would be practically no possibility of creating objectionable odors. A small amount of sand, which adheres to the sludge, is removed when air-dried sludge is taken from drying beds. The nitrogen content in the sludge is therefore lowered somewhat and its fertilizing value is less than that of sludge free from sand. Moreover, where land is costly and only a small tract is available, a centrifuge installation has the added advantage of requiring only a small space.

The performance of the centrifuge at Baltimore indicated that it is a process worthy of consideration and study. Additional experiments should be conducted in order to investigate and determine satisfactory ways of disposing of the effluent.

**Acknowledgments.**—The two centrifuges used in the above experi-

ments were loaned to the Bureau of Sewers of Baltimore by the Barth Engineering and Sanitation Co. The American patent rights under which these machines are built are controlled by Albert T. Otto and Sons, Inc., of New York City. The representatives of this company coöperated to the fullest extent in carrying on the work and bringing it to a successful completion. Full credit is due to those associates and assistants at the Baltimore sewage plant who shared in the investigations.

*Editor's Note: Discussion of this paper is invited. Please send written comments to the Editor, 845 So. Wabash Ave., Chicago, Ill.*

# Digestion of Activated Sludge[1]

BY WILLEM RUDOLFS[2] AND H. M. HEISIG[3]

A form of separate sludge digestion (lagooning) of activated sludge has been practiced for several years in Houston, Texas. Stanley (10)* reported that this method of sludge treatment has not been altogether satisfactory. During the summer months odors develop. Lagooning and trenching have also been practiced in Indianapolis, Canada and England. Separate sludge digestion tanks and Imhoff tanks have been used for the digestion of activated sludge in combination with fresh solids, notably at Essen, Germany, Chicago, Illinois, and Charlotte, N. C., but aside from a few laboratory experiments, reported more or less in detail, no accurate results are as yet available on the digestion of activated sludge alone.

Imhoff (4) concluded from laboratory experiments that digestion was most favorable in mixtures of activated sludge, fresh solids and ripe sludge. Our results were obtained with activated sludge alone. Rudolfs and Zeller (9) stated that properly seeded activated sludge digests more rapidly and with less odors than properly seeded fresh solids. Their figures show more rapid digestion of seeded activated sludge than a mixture of activated, fresh and ripe sludges as employed by Imhoff. Fair and Carlson (2) found that apparently activated sludge digests well by itself and that seeding enhanced the digestion processes. Wolman (11) reports briefly that unseeded activated sludge produced a "fairly well-digested material."

The digestion of seeded activated sludge on an operating basis is not only of theoretical value but also of practical importance. For small activated sludge plants the question is important because drying of activated sludge on sand beds may in summer time produce considerable odors. Lagooning is not wholly satisfactory and requires large areas. For larger plants it is of practical importance to know what can be done with the sludge when comparisons are made of pressing, drying or barging.

The experiments reported in this paper were made at the Milwaukee Sewage Treatment Plant. The Chief Engineer of the Milwaukee Sewerage Commission, Mr. Robert Cramer, who is intensely interested in all phases of sewage and sludge treatment, invited the senior author to assist in research work dealing with the digestion of screenings and activated sludge. The junior author has conducted the actual work and all analyses were made by him and his assistant, Mr. D. E. Bloodgood, to whom we are greatly indebted.

[1] *Journal Series Paper of the New Jersey Agricultural Experiment Station, Department of Sewage Disposal.*

[2] *Chief, Dept. Sewage Disposal.*

[3] *Research Chemist, Milwaukee Sewerage Commission.*

* *Numbers in text refer to references at end of article.*

## Methods and Material

A small tank with a gross capacity of 215 gallons was built for the experiment and tightly covered with an iron cover. The cover had an outlet for gases and on the side of the tank three outlets were so constructed that material for analyses could be taken from the bottom, middle or near the top of the tank and solids or liquid withdrawn from any of the outlets whenever desired. The tank was placed in a water bath at an average temperature of 81° F.

About 60 gallons of ripe sludge were secured from the Imhoff tank at Muskwonago, Wisconsin, and used for seeding. The experiments were started on June 24, 1927, by filling the remainder of the tank with about 155 gallons of activated sludge. The composition of the original material is given in Table I.

TABLE I
COMPOSITION OF MATERIAL

| Name | Solids % | Ash % | N as $NH_3$ % | pH | Gallons Used |
|---|---|---|---|---|---|
| Ripe sludge | 4.31 | 43.7 | 3.25 | 8.6 | 60 |
| Act. sludge | 3.82 | 36.5 | 6.29 | 7.6 | 155 |
| Mixture | 4.06 | 39.9 | 5.22 | 7.8 | 215 |

Beginning with the third day, pH determinations were made daily on material from the top, middle and bottom of the tank, and after 10 days, daily (except Sundays) determinations were made of total solids, ash and 24-hour biochemical oxygen demand of the material in the tank. The analyses were made during the whole period of the experiment, lasting 288 days. Daily temperature records were kept and nitrogen determinations were made daily for the first 6 months, with determinations on 3 to 4 day composites thereafter. The activated sludge added daily was analyzed for solids, ash and nitrogen. After the experiment had been running for 5 months the amount of grease in the activated sludge and digested material was determined for a period of about 110 days. An attempt to measure the gas production was made but the apparatus available and the construction of the tank made it practically impossible to secure accurate readings. The gases evolved were analyzed at weekly intervals.

## Results

The pH values of the material near the bottom and center of the tank were practically alike throughout the duration of the experiment. At the beginning the pH values of the material near the top varied somewhat from those obtained in the center and bottom of the tank, but later they were all nearly alike. The reaction remained above pH 8.0 for the first 35 days and dropped rapidly thereafter to 7.6–7.7 where it remained until the end of the experiment. For this reason no lime for reaction adjustment was

ever necessary. The changes in reaction for the first 66 days are illustrated in Figure 1.

After 20 days of digestion a beginning was made to add daily quantities of activated sludge; this was kept up intermittently until the 38th day and thereafter a daily charge was made of 5 gallons of activated sludge.

It is of interest to follow the daily fluctuations in B. O. D. (Figure 1).

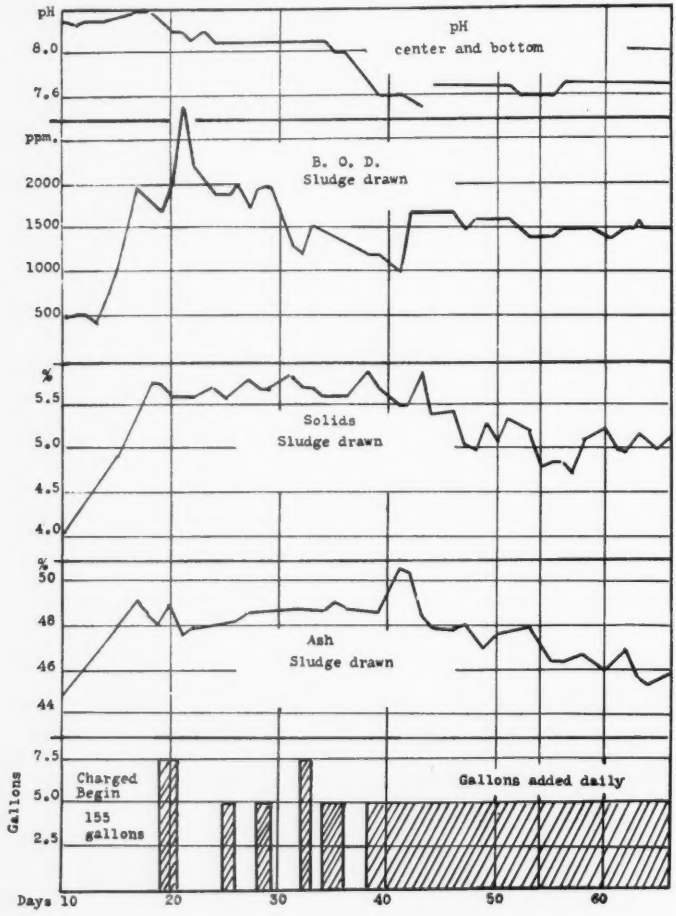



FIG. 1.—Graphic Representation of Analyses of Material Drawn and Activated Sludge Added during First 66 Days of Experiment.

Starting with a very low value of 500 p. p. m. it increased rapidly to 2900 p. p. m. after 29 days, dropping back to 2000 and after 40 days to 1000

p. p. m. After daily charging of activated sludge was well under way the values remained between 1200 and 1500 p. p. m. for the remainder of the experiment.

The solids concentration of the digested sludge increased rapidly from 4.06 to 5.75% during the first 18 days. The concentration then did not change until daily charging was under way. The ash content of the solids increased to about 49% and dropped after a month of continuous additions to 46%.

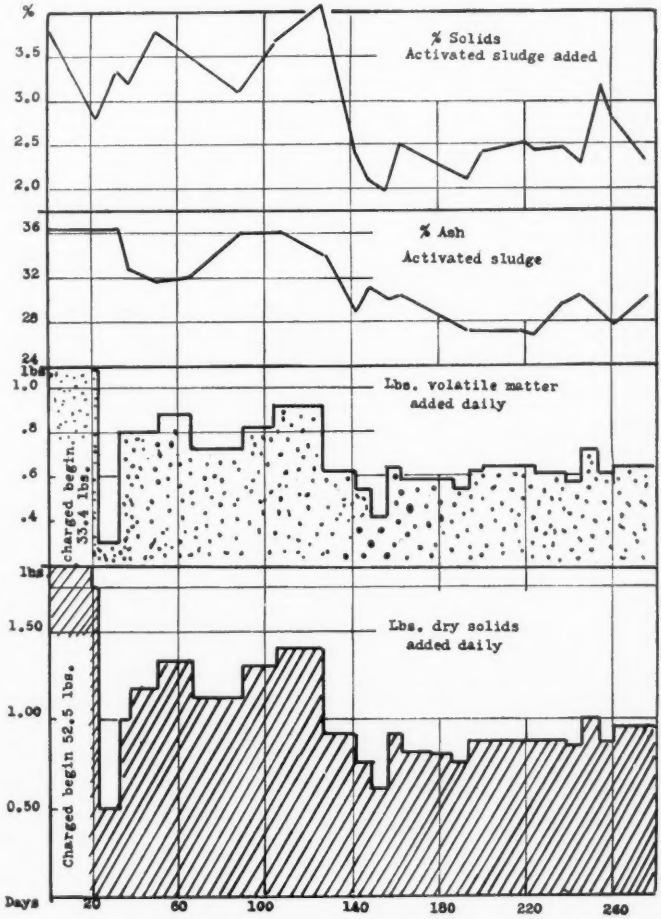



FIG. 2.—Variations in Concentration and Amounts of Activated Sludge Added to Tank.

After 35 days operation the cover of the tank was removed for inspection. There was practically no scum present. The tank contents were stirred. The stirring was followed by a drop of pH values, which remained at a constant level thereafter. If the drop of pH values was the result of the stirring no adequate explanation can be given at present. Ordinarily stirring of digestion mixtures results in slightly higher pH values since some of the dissolved $CO_2$ and $CH_4$ is driven out.

### Additions of Sludge

Although the volume of the daily addition of activated sludge remained constant, the charges were not alike because the solids concentration of the activated sludge varied from day to day. Figure 2 shows the weekly averages of the solids concentration throughout the whole period of the experiment. During the months of July to mid-November the solids concentration of the added sludge averaged 3.44%, whereas during the next half of the experiments the solids concentration averaged 2.40%. The ash content of the dry activated sludge dropped from 34.5% during the first $4^1/_2$ months to an average of 28% during the mid-November–March period. In order to have a clear picture of the load carried by the tank and to make interpretation of the analytical results more understandable, the material added daily in the form of dry solids and dry volatile matter have been graphically expressed in pounds of dry material (Figure 2). At the beginning of the experiment the amount of activated sludge added equaled $2^1/_2$ times the amount of dry ripe sludge used for seeding. During the first 106 days after charging was begun a daily addition of 1.25 pounds dry solids was made. During the first 126 days, including the initial charging of 155 gallons of activated sludge the addition was made on a daily basis of 1.46 pounds, whereas during the last 150 days of the experiment the daily addition on a dry solids basis was only 0.85 pound. It is evident that the experimental results during the first 126 days are of the greatest practical interest. Due to the fact that the ash content of the activated sludge was lower during the second period, the difference in quantities of volatile matter added was about 10% less than is indicated by the figures given for dry solids.

### Materials Drawn

The average solids concentration of the activated sludge added for the whole period was 2.40%, with an average ash content of 31.2 per cent. The average solids content of the sludge withdrawn was 4.52% with an average ash of 42.9 per cent. The variations in sludge concentration and ash content are shown in Figure 3. If these curves are compared with the curves showing the results for the activated sludge added, it can be seen that the concentration of the sludge added and drawn followed each

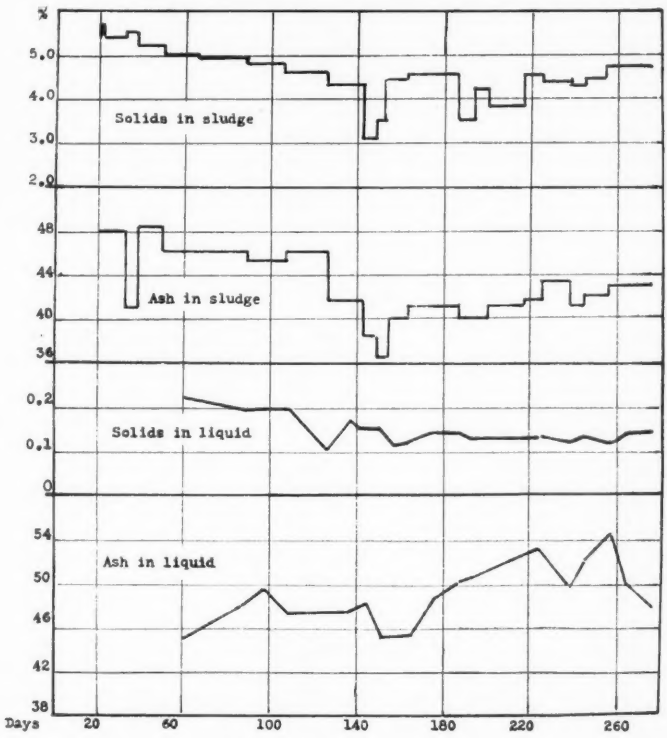



FIG. 3.—Variations in Solids and Ash Content of Sludge and Liquid Drawn.

other in a general way, although the concentration of the material drawn did not decrease to such a large extent in the second half of the experiment as the solids concentration of the activated sludge. It is clear that the variation in concentration of the sludge drawn is related to the concentration of the material charged, but it is interesting to note that the solids condensed to a rather uniform concentration. The reduction in volume of solids during the whole period amounted to 89%, disregarding the amount decomposed.

The supernatant liquid in the tank was at all times free from suspended solids as is indicated by the curves in Figure 3 for liquid drawn. The average percentage of total solids was 0.13% with an average ash content of 45.4 per cent. At no time were the solids in the liquid higher than 0.22%, indicating that separation of the liquid and sludge took place rapidly.

## Solids Reduction

The total amount of dry solids added was 255.8 pounds and the amount

drawn in the form of sludge and liquid, plus what was left in the tank, was 198.8 pounds, or a reduction of solids of 28.4 per cent. The reduction in volatile matter amounted to 49.0% with an ash increase of 37.5 per cent. With settled sewage solids containing about 25% ash and digested at 68–70° F. on a digestion schedule of 40 days, a reduction of solids of from 30 to 35% might be expected. The activated sludge added contained a greater ash content and the temperature of digestion was higher but the time of digestion was considerably shorter than is usually required for settled solids.

## Digestion Schedule

On a volume basis a 30-day digestion schedule was maintained throughout the duration of the experiment. However, the solids concentration of the activated sludge added varied considerably. It is therefore of particular interest to calculate what the actual accomplishments were on a dry solids basis during the whole course of digestion and also during the two distinct periods of digestion mentioned previously.

Some years ago we reported studies (6) in which it was shown that under normal conditions not more than 2% fresh domestic sewage solids can be added daily (on a dry basis) to an unheated digestion tank. This quantity can be increased under more favorable temperature conditions (80° F.) to 3.5–4.0 per cent.

When the Milwaukee experiment was started it was planned to run a digestion schedule of 30 days, equivalent to a daily addition of 3.33% dry solids. Calculations show that actually during the whole period a daily addition of 4.3% was made, corresponding to a digestion schedule of 23 days. However, the results for the first 126 days show what the tank could handle. At the beginning of the experiment the amount of activated sludge added was sufficient to last presumably for 37–40 days, or until the peak of digestion activities was over. After 20 days, addition of definite quantities was begun. During the first 106 days (after charging started) the daily addition amounted to 5.75%, equivalent to a storage period of 17.5 days. If we consider that the initial charge of activated sludge was large, and daily addition was begun when the material was not yet ripened, and include this charge with the additional 20 days, we find that the daily addition amounted to 6.75%, equivalent to a storage period of 15 days. These results indicate, therefore, that properly seeded activated sludge digests more rapidly than fresh solids, and that at 81° F. not more than 17–18 days are required.

## Loss of Nitrogen

The loss of nitrogen during the digestion of fresh sewage solids is considerable. It may amount to 30% or more. How the nitrogen is lost is still

an open question, but that a goodly number of pounds are lost is reported elsewhere (8). There is no doubt that under certain conditions considerable nitrogen is lost in the form of ammonia. A good illustration was afforded us during the summer of 1927 when chlorination experiments were in progress at Plainfield, N. J. Occasionally the chlorine escaped into the air, and while drifting over the Imhoff tanks reacted with the ammonia coming from the tanks, causing a white cloud to hover over the tanks. It has previously also been demonstrated by one of us (5) that ammonia is actually evolved from mixtures of sludge undergoing digestion in the laboratory. On the other hand, when vessels containing digesting sludge are tightly closed and the material analyzed (liquid as well as sludge), there is no loss of nitrogen (3). It is well known that part of the nitrogenous substances become soluble during the process of decomposition. In the course of digestion the ammonia in the liquid increases at first and then gradually decreases; the ammonia compounds may be re-assimilated by

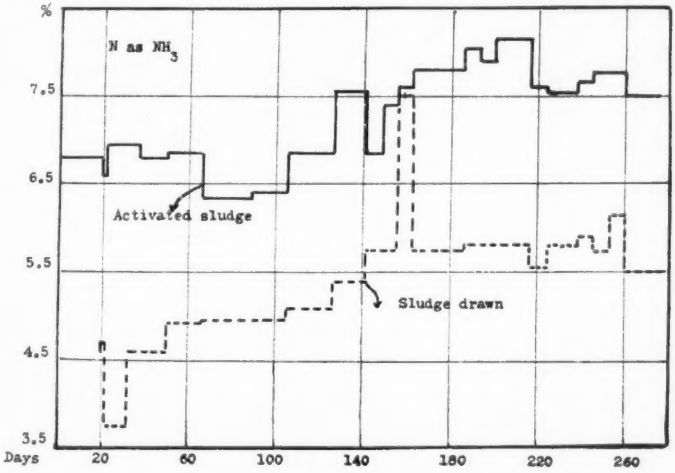



FIG. 4.—Variations in Nitrogen Content of Material Added and Withdrawn.

the microflora, resulting in no loss, but even a possible increase. The conditions are different, however, when sludge is digested on a large scale in a tank. Whenever sludge is added it displaces an equal volume of liquid, which is discharged from the tank, and the nitrogen is lost. Another possibility is that small amounts of gaseous nitrogen escape, as indicated by the fact that small percentages of nitrogen are usually reported in analyses of gas from digesting sludge, without the presence of oxygen. In the case under discussion the nitrogen "lost" went out most likely with the supernatant liquid.

It is of interest to compare the nitrogen content of the activated sludge added with the nitrogen content of the sludge drawn. Figure 4 illustrates the variations in nitrogen (as ammonia). It will be seen that the general trend of both curves is somewhat the same, indicating, possibly, that a certain definite quantity of nitrogenous matter is decomposed during the digestion process. The average percentage of nitrogen as ammonia in the activated sludge added was 6.78, or a total of 20.04 pounds. The average ammonia in the sludge amounted to 4.20 per cent. On a percentage basis the loss would amount therefore to 38 per cent and on a weight basis 32 per cent.

It is interesting to note the differences in ammonia content of the activated sludge between the summer and fall months and the winter months, giving considerable room for speculation on the habits of the people and differences in manufacturing processes.

## Digestion of Grease

The percentage of grease in activated sludge is rather low as compared with fresh sewage solids or screenings. Analyses of the grease content of the activated sludge added and the sludge withdrawn were made from December 5 to March 26, 1928, a period of 112 days. The average grease content of the activated sludge was 6.29% and of the sludge drawn 5.09 per cent. It is intended to discuss the question of digestion of grease briefly in a subsequent paper.

## Gas Production

As stated before no accurate results are available on the amount of gas produced. It might be expected, however, that activated sludge will produce lower amounts of gas than fresh sewage solids. The analyses of the gas for methane were not reliable since in all instances considerable quantities of oxygen were present, varying from 3.4 to 7.9 per cent. The carbon dioxide content varied between 17.2 and 35.3 per cent.

For the first 164 days, when the load to be carried by the tank was considerably greater than during the second part of the experiment, the $CO_2$ content of the gas varied between 20.4 and 26.2% with an average of 23.1%, whereas during the second part of the experiment the variations were much greater, namely from 17.2 to 35.3% with an average of 27.4 per cent. Not less than 85% of all analyses made during the second part of the experiment showed 26.8 or more per cent $CO_2$ while during the first 164 days 70% of the analyses showed a $CO_2$ content of the gas of 24.2 or below, with only one analysis of 26.2 per cent. Some years ago, when we searched for a practical, simple method of diagnosing the course of digestion in an Imhoff tank, a method which would reveal approaching trouble, the determination of the $CO_2$ content of the gas seemed one of the most promising for the

purpose. In the Annual Report for 1923–24 (7) several hundreds of analyses were presented from which the conclusion was drawn that the $CO_2$ content of the gas was a fairly good index of the state of digestion, and that digestion was not proceeding satisfactorily when there was a marked increase in the $CO_2$ content. It was found that this test could be used as an index of approaching trouble. Since then Buswell (1) has called attention to the same correlation between tank behavior and $CO_2$ content of the gas.

In the experiment under discussion the $CO_2$ content of the gas was *lowest* when digestion capacity of the tank was forced and *highest* (also with greatest fluctuations) when the load on the digestion capacity diminished. It would seem, therefore, that in this particular case the load on the digestion capacity of the tank was not directly responsible for the rate of $CO_2$ production. A comparison of the composition of the material added with the $CO_2$ content of the gas shows that the nitrogen content of the material was greatest during the second part of the experiment when the $CO_2$ content of the gas was highest. However, although the percentage nitrogen of the material added was higher during the second part of the experiment the absolute quantities added were less. There is, therefore, no direct evidence that the quantities of nitrogenous substances were directly responsible for the fluctuations and increase in $CO_2$ content.

No data are available concerning the grease content of the activated sludge during the first part of the experiment. Analyses are available for the months December, 1927–March, 1928. The percentage of grease in the dry sludge in December, 1927, was about 6%, dropped to 5% in January, 1928, and from then on rose steadily until March, 1928, when about 8% was present. The data in Table IV indicate that there may be some relation between the reduction of grease and increase of carbon dioxide. The $CO_2$ figures represent the average for these months, and the calculated percentages of grease reduction are based upon the percentages of grease in the activated sludge and in the ripe sludge. It would seem from these figures that in this experiment the composition of the gas was not influenced primarily by the amount of solids added nor by the composition of the sludge, but was modified by the *rate* of digestion of the grease present.

It is of interest to state that at the beginning of the experiment small quantities of hydrogen were present, but no traces were found when the experiment had been running for some time.

## Temperature

The temperature of the digesting material was maintained by a water bath surrounding the tank. The average temperature was 81° F. although some extreme fluctuations occurred during a few days. From a large number of digestion experiments with fresh sewage solids it has been established

## Drying of Sludge

that a temperature of 82° F. is about the optimum for digestion. This optimum temperature was also assumed to hold for the digestion of activated sludge.

The appearance of the sludge drawn indicated that it was well digested. The sludge was black and drained readily. It was placed on small glass-covered drying beds (2 ft. square) which were replicas of large sand beds as far as proportion and depth of sand were concerned. Sludge was put on about 9–12 inches deep and samples for analyses were taken from the center of these beds. Some of the results obtained are given in Table II. It will

TABLE II

DRYING OF SLUDGE ON SAND BEDS

| % Moisture, Applied Sludge | Days on Bed | % Moisture Removed Sludge | Month |
|---|---|---|---|
| 95.0 | 20 | 37.8 | August |
| 94.5 | 17 | 25.0 | August |
| 95.0 | 16 | 23.0 | August |
| 95.1 | 15 | 26.1 | August |
| 94.8 | 25 | 35.0 | August |
| 95.2 | 24 | 32.9 | August |
| 95.0 | 22 | 69.5 | October |
| 95.3 | 21 | 73.4 | October |
| 95.2 | 19 | 74.0 | October |
| 95.4 | 17 | 76.1 | October |
| 95.2 | 16 | 76.2 | October |
| 95.5 | 14 | 80.0 | October |
| 95.6 | 12 | 79.2 | October |
| 95.7 | 10 | 83.2 | October |
| 95.6 | 8 | 80.3 | October |
| 95.4 | 6 | 79.7 | October |
| 95.5 | 5 | 82.2 | October |
| 95.3 | 1 | 86.6 | October |
| 95.5 | 6 | 85.7 | November |
| 95.6 | 3 | 87.4 | November |
| 95.5 | 2 | 87.0 | November |

be seen that the sludge dried during warm weather much more rapidly than during the late fall. Although the material drained well, it is evident that covering with glass did not solve the problem of rapid drying. Some of the dried sludge was piled up and ignited. It burned slowly, gave off considerable heat and some disagreeable odors. The resultant comparatively small quantity of ash was reddish brown. The fact that the material could be burned shows that it dried well. This method of further reduction of the volume might be of value where limited area is available for ultimate disposal.

## Discussion

The minimum, maximum and averages of the pertinent results obtained

are given in Table III. From the percentage solids recorded it is evident that there was a clear separation of sludge and liquid. The ash content of the liquid was somewhat higher than that of the sludge drawn.

TABLE III

SUMMARY OF ANALYTICAL RESULTS

| | Min. | Max. | Av. |
|---|---|---|---|
| Solids added: | | | |
| Solids % | 1.96 | 4.83 | 2.40 |
| Ash % | 26.6 | 36.5 | 31.2 |
| Solids drawn: | | | |
| Solids % | 3.10 | 5.69 | 4.52 |
| Ash % | 36.3 | 48.6 | 42.9 |
| Liquid drawn: | | | |
| Solids % | 0.11 | 0.22 | 0.13 |
| Ash % | 38.5 | 52.9 | 45.4 |
| pH sludge | 7.4 | 8.4 | 7.9 |
| B. O. D. sludge drawn p. p. m. | 1140 | 1990 | 1590 |
| N as $NH_3$ %: | | | |
| Activated sludge | 5.84 | 7.64 | 6.78 |
| Sludge drawn | 3.24 | 7.02 | 4.20 |
| Grease %: | | | |
| Activated | 4.60 | 8.28 | 6.29 |
| Sludge | 3.75 | 5.96 | 5.09 |
| Temperature ° F. | 77.1 | 87.4 | 81.0 |

The ratio of carbon to nitrogen in fresh solids from normal sewage varies from 6:1 to 13:1, depending upon the locality (town) and the time of the year. In activated sludge the nitrogen content is higher, probably partly due to re-assimilation of nitrogen by the micro-organisms in the floc and partly to easily oxidizable carbonaceous material in the sewage being oxidized in the aeration process. On the basis of dry solids from 3.5 to 4.0% nitrogen and from 25 to 30% carbon would be a fair average for domestic fresh solids. The average ammonia content of the activated sludge used in these tests was 6.29%, equivalent to 5.58% nitrogen. This is considerably higher than the nitrogen content of a number of samples of fresh sewage solids collected from different plants and analyzed in the laboratory of the New Jersey Sewage Sub-station. No analyses were made of the carbon content of the activated sludge digested in the Milwaukee experiments and therefore we cannot compare results for carbon and nitrogen directly, but if we compare the reduction of nitrogen with the total reduction of volatile matter, we find that the volatile matter reduction of the activated sludge added amounted to 49% and the percentage of ammonia reduction amounted to 32 per cent. Calculation based on the number of pounds of grease added and drawn shows a reduction of 36 per cent. In all cases the material left in the tank at the end of the experiment is taken into consideration. Fatty substances are composed mainly of carbon, plus hydrogen

and oxygen. The results indicate that this type of carbonaceous material decomposed more slowly than the aggregate solids determined as volatile matter. It would therefore seem that those carbonaceous materials of a non-fat-like nature decomposed most rapidly, followed by grease, and finally by nitrogenous substances. (It should be kept in mind what has been said about the loss of nitrogen in the earlier part of this paper.) The fibrous substances difficult to decompose are left behind as a humus-like sludge. The differences in the rate of decomposition of the various groups of substances are not extreme. The digestion time employed in this experiment was apparently sufficient for the decomposition of all unstable substances present in the activated sludge.

TABLE IV

RELATION BETWEEN $CO_2$ CONTENT OF GAS AND GREASE REDUCTION

| Month | Grease added daily Grams | Reduction in grease % | $CO_2$ in gas % |
|---|---|---|---|
| December | 24.0 | 8.45 | 22.9 |
| January | 19.8 | 11.90 | 24.8 |
| February | 22.2 | 21.20 | 29.3 |
| March | 31.6[a] | 26.20 | 28.2 |

[a] Part only short time in tank.

From the results obtained it is evident that the effective digestion capacity required for digestion of activated sludge is determined by the same factors that govern fresh solids digestion, namely, upon (1) the concentration of the activated sludge, (2) physical constants such as temperature and rate of addition and (3) upon efficiency of operation. Since in this experiment activated sludge digested more rapidly than fresh solids, and separated more completely from the liquid than do fresh solids, the effective digestion capacity required for activated sludge digestion is indicated to be less than for the digestion of fresh solids. If we consider the fact that the removal of suspended solids by the activated sludge process is ordinarily at least 30% more than the removal by any settling device now in use, and the digestion time for activated sludge constitutes not more than $^2/_3$ of the digestion time required for the digestion of properly seeded fresh solids, the larger quantity of activated sludge to be handled would not require any larger digestion capacity than the sludge obtained by preliminary muthods of sewage treatment.

## Summary

A semi-plant scale experiment for the digestion of activated sludge at an average temperature of 81° F. has been conducted at Milwaukee, Wisconsin for a period of 288 days. During 268 days a definite volume of activated sludge was added daily. The results show that 49% of the volatile matter added as activated sludge decomposed. Decomposition of grease

amounted to 36% and the nitrogen lost was 32 per cent. During the first 106 days the daily addition of sludge amounted to 5.75% (on a dry basis), equivalent to a digestion schedule of 17.5 days. Addition of dry solids for the whole period amounted to 4.3%, equivalent to a digestion schedule of 23 days. The digestion schedule of 17.5 days maintained for $4^1/_2$ months produced a good, well-draining sludge, which had no other odor except the usual "gas odor" associated with methane production. No accurate measurements of the volume of gas produced could be made. The $CO_2$ content of the gas was similar to that of gas produced from the digestion of fresh solids.

It is concluded that activated sludge digests more rapidly than fresh sewage solids, and that no greater digestion capacity is required, in spite of the fact that more solids must be treated from the activated sludge process than from settling processes.

## References

1—Buswell and Strickhouser, *Ind. Eng. Chem.*, **18,** 407 (1926).

2—Fair and Carlson, *Jour. Boston Soc. Civ. Eng.*, **14,** 9 (1927).

3—H. Heukelekian and W. Rudolfs, *Ind. Eng. Chem.*, **20,** 177 (Feb., 1928).

4—K. Imhoff, *Eng. News-Rec.*, **94,** 937 (June 4, 1925).

5—Rudolfs, *et al.*, Annual Report New Jersey Sewage Sub-station 1923.

6—Rudolfs, *et al.*, Annual Report New Jersey Sewage Sub-station 1924–25 and 1925–26.

7—Rudolfs, *et al.*, Annual Report 1923–24 (pp. 17–23).

8—W. Rudolfs, *Soil Science*, **16** (Dec., 1928).

9—W. Rudolfs and P. J. A. Zeller, *Pub. Works*, **58,** 7 (July, 1927).

10—W. S. Stanley, Proc. Ninth Texas Water Works School, 288–292 (1927).

11—Abel Wolman, Rpt. Bur. San. Eng. Md., pp. 15–16 (1927).

# Gas Production from Sewage Sludge

BY S. I. ZACK[1] AND G. P. EDWARDS[2]

## General Status of Gas Production

Considerable interest is being displayed in this country and abroad, particularly in Germany, in the production and utilization of gas from sewage sludge. Most of the data thus far reported have been obtained from tests conducted in the laboratory or at plant installations which may be classed as not having passed beyond the experimental stage.

The laboratory tests have been carried on by Fair and Carlson at Harvard, Rudolfs at New Brunswick, N. J., Fries, Sierp and Prüss in Germany, Hatfield at Decatur, Buswell at Urbana, Illinois and Mohlman, Edwards and Ruchhoft at the Sanitary District of Chicago. Practically all investigators have found the same factors, such as composition of sludge, time of digestion, temperature, and pH control, to have an important bearing on the quantitative production of gas. It is generally agreed that below 50° F. gasification practically stops. At 60° to 65° F. a critical point occurs where the rate of gasification increases rapidly to about 77° F., with a decreasing rate at higher temperatures. All results also indicate that gasification proceeds most favorably when the sludge is at a pH of 6.5 to 7.6.

There is, however, a wide variation of opinion as to the quantity of gas and the rate of production from mixtures of sludges, and the total quantities of gas that can be produced per pound of organic matter. An attempt has been made to set up definite proportions for the seeding of ripe sludge, fresh solids and activated sludge, at which sludge digestion and gas production proceed most rapidly and favorably. A critical study of these results shows some discrepancies which have not as yet been explained.

There are at present only a few installations of working size which have been in operation for a sufficiently long period to demonstrate the possibility of recovering the gas produced in the digestion of sewage sludges on a practical scale.

Gas has been collected and results recorded accurately for periods of a year or more at Antigo, Wisconsin, Stuttgart and Essen, Germany, and the Sanitary District of Chicago. At Plainfield, N. J., heated separate sludge digestion tanks provided with gas collectors have been operated for over a year, but because of a faulty cover, not all the gas evolved was collected or measured. Imhoff tanks at Newcastle, Pa., are equipped for gas collection, but very low rates of gas production were reported during the first year of operation. Recent results are much more satisfactory. The Imhoff tanks at Decatur, Ill., are also equipped for gas collection.

[1] *Asst. Engr., The Sanitary District of Chicago.*
[2] *Prin. Asst. Chemist, The Sanitary District of Chicago.*

Some data on gas collection have been reported by Imhoff, Sierp and Prüss based on results obtained at Essen, Germany, on both experimental and full-scale operation basis.

Digestion tanks from which gas is produced may be classified as heated or unheated. Heating of sludge in Imhoff tanks does not appear to be practical because of the inter-connection of the settling and digestion compartments through the slot. Rudolfs has advocated the heating and pH control of separate sludge digestion tanks. Such tanks are in operation and operating results are recorded at Antigo, Plainfield, the Des Plaines River Testing Station of the Sanitary District of Chicago, Essen and Stuttgart, Germany. At these plants a uniform temperature is maintained in the digestion tanks by the use of some of the gas evolved, thus speeding up the digestion time and producing gas at a constant rate regardless of seasonal temperature changes. Since more gas is required for heating the sludge in the winter, the largest amount of gas to be sold for commercial use is available in summer.

It has not been found necessary to control the pH of the sludge in Des Plaines tank, which operates on a mixture of fresh solids and activated sludges. At Newcastle, Pa., as much as 30 tons of lime, spread over a period of four months, was used before digestion favorable for gas production was obtained.

Both the laboratory tests and full-scale tanks have produced a rich gas composed of about 75 per cent methane, with a heating value of 700 to 800 b. t. u. per cubic foot.

In reporting the quantities of gas produced per pound of volatile matter an attempt should be made to account for ripe sludge, added for seeding, which has not undergone complete digestion. Such sludge, when mixed with fresh solids or activated sludge, again produces considerably more gas.

In some cases the computed weight of the gas is higher than the weight of digested volatile solids from which it was produced. To a certain extent this is unavoidable, but in any case should be within the limits of accuracy of sampling and analysis.

## Sampling and Analysis of Sludge

At large installations where the gas is reported in cubic feet of gas per pound of volatile matter, it is important that analyses of solids from which results are computed cover the same period as the recorded gas production and also that all the gas produced be measured. At Antigo, the most recent results indicate nearly 100 per cent gasification of volatile solids; whereas, at Plainfield not all the gas is recovered. Unless precautions are taken in recording results, such figures are misleading to the engineer and form no basis on which to make estimates for design.

In order to summarize existing information we have made a critical study of the available data, including unpublished results from the Sanitary District of Chicago. Laboratory experiments and plant-scale tests are discussed separately. Only the essential data relating to gas production have been included, in order to avoid digression into other phases of sludge digestion.

## DISCUSSION OF LABORATORY DATA

### Factors in Digestion of Fresh Solids

*Seeding.*—Seeding, temperature, and pH control are the most important of the factors which influence the rate of sludge digestion. All investigators agree that the rate of digestion is accelerated by proper seeding of fresh solids with well-digested sludge. The sludge used for seeding should be in an active state of gasification. Ripe sludge which has long passed this stage is useless. The addition of about 1 part ripe sludge to 2 parts fresh solids, based on the volatile matter, is usually satisfactory. In a tank to which fresh solids are continually being added Rudolfs[1,*] recommends the addition of 2 parts of fresh dry organic solids to 98 parts of ripe sludge each day. This is computed for a 50-day digestion period at 70° F.

*Temperature.*—Gasification usually starts at about 10° C. and the rate increases rapidly with rise in temperature. According to Rudolfs[2] and Baity,[3] maximum gas production occurs at about 25–28° C. and according to Hatfield[4] at about 32–33°. Hatfield[4] and Baity[3] report a decrease at a temperature higher than the optimum. Table I shows the effect of temperature on the digestion of seeded fresh solids as determined by Imhoff[5] and Baity.[3]

TABLE I

TIME REQUIRED FOR DIGESTION

| | Temperature ° C. and Time in Days | | | | | |
|---|---|---|---|---|---|---|
| Observer | 5° | 10° | 15° | 20° | 25° | 37° |
| Imhoff[5] | 210 | 120 | 60 | 30 | 21 | .. |
| Baity[3] | ... | 270 | .. | 70 | 54 | 58 |

Baity[3] believes there is a critical point between 15° and 20°, probably 16–17°, where a slight rise in temperature causes a rapid increase in rate of digestion.

*pH Control.*—Control of hydrogen-ion concentration has been shown to be of value in shortening the period of acid digestion and thereby the total digestion period. Rudolfs,[6] Baity[3] and Fair and Carlson[7] recommend that the pH be maintained between 6.8 and 7.6. Fair and Carlson[7] suggest that the value 6.8 may be best during the initial stage of digestion and that it should be increased to 7.2 or more during the final stage.

*Effect of Pressure and Vacuum.*—There has been some discussion in the literature about the effect of pressure and vacuum on sludge digestion.

*Numbers in text refer to bibliography at end of article.

Sierp[8] found that, under a pressure corresponding to 22 inches of mercury, no decrease in gasification occurred. Prüss[9] claims that digestion of sludge under pressure, that is at the bottom of a tank, is retarded because of increased solubility of gases toxic to the bacteria responsible for digestion. He proposes to circulate sludge from bottom to top of the tank, thus liberating dissolved gases by reduced partial pressures. With this arrangement, he claims to have obtained digestion in about one-half the time necessary for quiescent sludge.

Blunk[10] and Rudolfs[11] reported that stirring did not aid digestion. Their experiments were carried out on a laboratory scale so that the sludge was not under pressure. Under these circumstances it is reasonable to conclude that stirring would have no great effect on digestion.

With diminished pressure, Sierp[8] obtained an increase in gas production which he explained by the decrease in solubility. He did not obtain a more complete digestion. Cohen[12] reported that at Claiborne, Texas, remarkably improved results were obtained in both Imhoff tank and sprinkling filter operation with a decrease in pressure amounting to slightly less than an inch of mercury.

## Experimental Work on Pressure and Vacuum

In order to determine the effect of alternate pressure and vacuum on the digestion of sludge, two 1-liter samples of fresh solids, seeded with 1 part ripe sludge to 2 parts fresh solids on the basis of their volatile solids, were digested in 1-gallon Woulff bottles at room temperature in the Main Laboratory of the Sanitary District of Chicago. The sludge was obtained from an experimental Dorr Clarifier at the Des Plaines River Treatment Works. One sample was digested at atmospheric pressure and the other under a pressure of 20 inches of mercury. The apparatus used is shown in Figure 1.

After the mercury column H was adjusted so that gas would bubble through at a pressure of 20 inches it was connected to the Woulff bottle and the gas-collecting apparatus. Valve V was closed and the gas from the sludge was allowed to build up a pressure of 20 inches of mercury. This occurred in seven days. There-

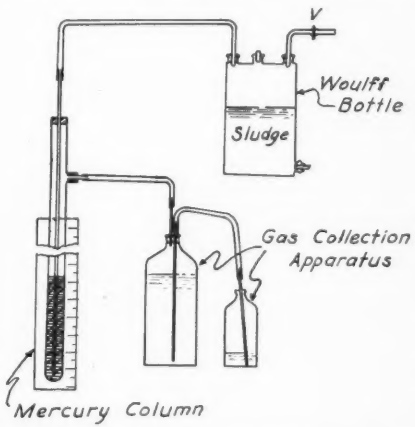



FIG. 1.—Pressure Gas Collection Apparatus.

after the gas bubbled through the mercury and was collected over water saturated with sodium chloride. All gas readings were made at atmospheric pressure. Eleven times during the digestion period, the pressure system was evacuated through valve V to a negative pressure of about 20 inches of mercury. This evacuated gas was returned to the sludge bottle until the pressure was the same as before evacuation. The excess gas from the evacuation, representing the gas in solution, was measured. The evacuations were not made at regular intervals but more frequently during the period of maximum gasification and less often thereafter.

From the curve in Figure 2 it can be seen that the gas production from the two samples coincided very closely throughout the period of digestion.

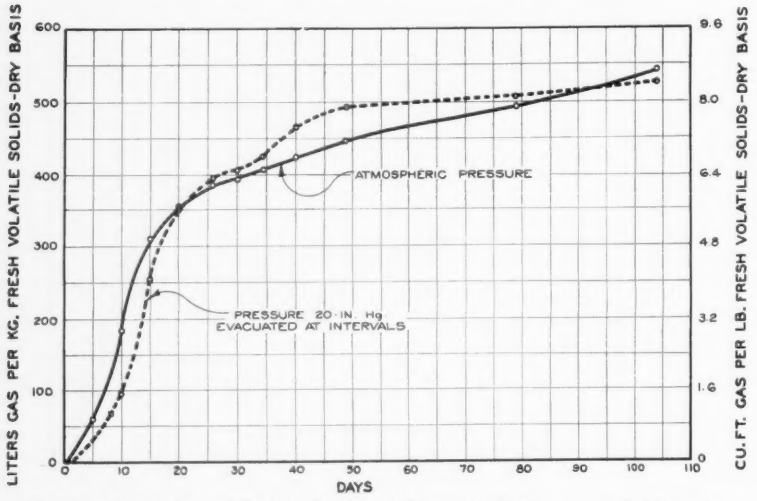



FIG. 2.—Comparison of Gas Production at Atmospheric Pressure and Alternate Pressure and Vacuum.

The total gas accumulated amounted to about 520 liters per kilogram of fresh organic solids in each case. This alternate pressure and vacuum was an exaggeration of Prüss'[9] idea. The results would seem to indicate that release of pressure intermittently does not produce more gas or better digestion than is obtained from sludge digested at atmospheric pressure.

To determine the effect of diminished pressure, two samples of unseeded fresh solids were digested at room temperature. One sample was kept at atmospheric pressure and the other under a continuous vacuum of about 15 inches of mercury. The sludge was digested in a gallon Woulff bottle connected with a manometer and suitable apparatus for the collection of gas as shown in Figure 3. The apparatus was manipulated as follows:

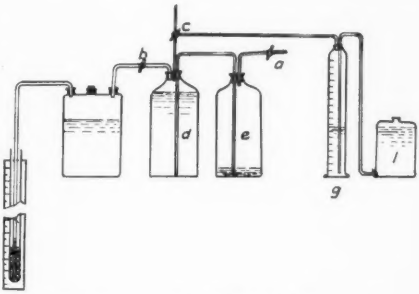



FIG. 3.—Vacuum Gas Collection Apparatus.

In the beginning, valve *c* was closed to bottle *d*. Valve *b* was opened and the vacuum applied at *a*. When a reading of 15 inches was recorded on the manometer, valve *b* was closed. Then the vacuum was disconnected from *a* and applied at *c* until the salt solution in *d* was brought up to a mark in the neck of the bottle. Valve *c* was then closed to bottle *d* and vacuum again applied at *a* until a vacuum slightly in excess of 15 inches was obtained. Valve *b* was again opened. The whole system was maintained at a vacuum of about 15 inches at all times. When a gas reading was made, valve *a* was manipulated until exactly 15 inches showed on the manometer. Valve *b* was closed and valve *a* was opened to the air to allow the gas in bottle *d* to contract to about atmospheric pressure. The graduated cylinder *g* was filled by raising the leveling bottle *l*. After making the proper connections through valve *c*, the gas from bottle *d* was drawn into the cylinder *g* by lowering the leveling bottle *l*. When the salt solution in *d* was brought up to the mark in the neck, valve *c* was closed, the liquid in *g* and *l* were brought to the same level and the volume of gas measured at atmospheric pressure. After the reading, *c* was closed, the apparatus was again evacuated through *a* to a little more than 15 inches, and valve *b* was opened.

If in the evacuated sample we neglect the gas in solution and above the surface of the liquid as recorded by the first day's reading, the curves as shown in Figure 4 are nearly identical.

## Digestion of Activated Sludge

Numerous laboratory and small-scale experiments have been carried out to determine the digestibility of activated sludge and the effect of mixing it with fresh solids and ripe sludge. Table II summarizes some of the results reported by Imhoff,[13] Rudolfs,[14] and Fair and Carlson.[15] Imhoff[13] incubated his samples at 17° C., Rudolfs[14] at 20° C., and Fair and Carlson[15] at 37° C. As shown in Table II, Fair and Carlson[15] agree with Imhoff[13] that a mixture of seeded fresh solids and activated sludge digests most rapidly and seeded activated sludge second. Rudolfs,[14] however, places seeded fresh solids first, next the seeded mixture of fresh solids and activated sludge, with activated sludge in third place.

It is interesting to note that Rudolfs[14] and Fair[15] obtained almost identical results for the gas produced by seeded samples with the exception

of the value of 10.85 cu. ft. of gas per lb. of organic matter for seeded activated sludge, as obtained by Rudolfs.[14] Imhoff[13] found a similar relation within the series but his results are much lower than those obtained by the other two investigators. Rudolfs'[14] value of 10.85 cu. ft. of gas per lb. of organic matter for seeded activated sludge is from two to three times as high as obtained by other investigators. Rudolfs'[14] gas yield for unseeded activated sludge is also very high as compared with Imhoff's[13] and Fair's[15] results.

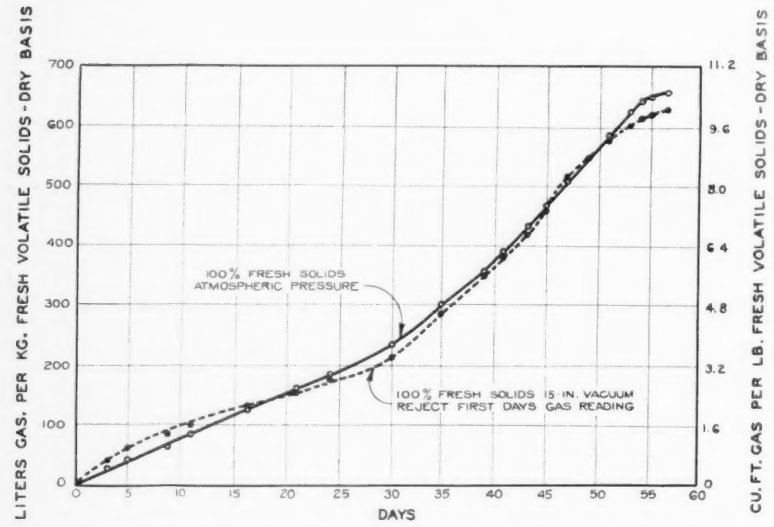



FIG. 4.—Comparison of Gas Production under Vacuum and at Atmospheric Pressure.

TABLE II

ACTIVATED SLUDGE MIXTURES YIELD OF GAS AT TIME FOR DRAWING SLUDGE

| | Gas in Cubic Feet per Pound Volatile Solids | | | | | |
|---|---|---|---|---|---|---|
| | Imhoff 17° C. | | Rudolfs 20° C. | | Fair 37° C. | |
| Mixture | Gas | Days | Gas | Days | Gas | Days |
| Activated + Fresh + Ripe | 3.6 | 30 | 6.87 | 40–45 | 6.5 | 35 |
| Activated + Ripe | 3.44 | 50 | 10.85 | 50–55 | 5.5 | 36 |
| Fresh + Ripe | 3.44 | 60 | 6.56 | 30–35 | 7.5 | 49 |
| Activated | 0.40 | 70 | 6.27 | 50–55 | 3.68 | 42 |

*Unseeded Mixtures.*—Experiments on the digestion of activated sludge, alone and mixed, with settled solids were started Sept. 24, 1926, in the Main Laboratory of the Sanitary District of Chicago. Various mixtures of activated sludge and fresh solids from the Des Plaines Treatment Works were set up in the following proportions:

PER CENT COMPOSITION OF SLUDGE MIXTURES

| Wet Basis | | Dry Basis | | Volatile Solids Basis | |
|---|---|---|---|---|---|
| Fresh Solids | Activated Sludge | Fresh Solids | Activated Sludge | Fresh Solids | Activated Sludge |
| 100 | 0 | 100 | 0 | 100 | 0 |
| 80 | 20 | 90 | 10 | 93 | 7 |
| 67 | 33 | 80 | 20 | 83 | 17 |
| 50 | 50 | 67 | 33 | 70 | 30 |
| 33 | 67 | 50 | 50 | 55 | 45 |
| 0 | 100 | 0 | 100 | 0 | 100 |

It is apparent from the curves in Fig. 5 that rates of gas production in mixtures cortaining 100%, 93%, and 83% fresh solids followed each other very closely throughout the digestion period. The 70% and 55% fresh

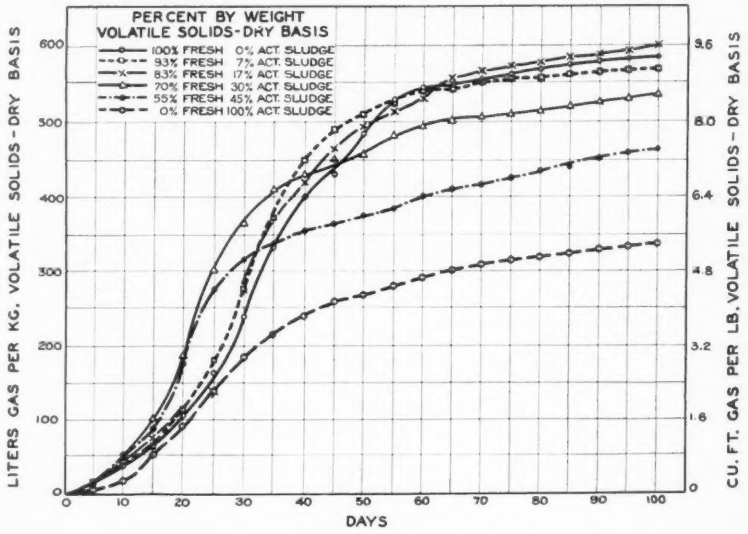



FIG. 5.—Gas Production from Unseeded Mixtures of Fresh and Activated Sludge at 25° C.

solids mixtures were considerably lower in total gas production although the rate up to 30 days was slightly greater than that of the mixtures containing larger amounts of fresh solids. The activated sludge alone formed only about one-half as much gas as was obtained from the fresh solids alone. The pH observations, as shown in Table III, indicate that these sludges did not become so acid as has been reported by Rudolfs[16] and Fair and Carlson.[17] The fresh solids had an initial pH value of 6.3. This was a minimum and it rose steadily until in 13 days neutrality was reached.

TABLE III

HYDROGEN-ION CONCENTRATION AS pH OF MIXTURES OF FRESH AND ACTIVATED SLUDGE AT 25 DEGREES C.

| Days | 100% Fresh 0% Activated | 93% Fresh 7% Activated | 83% Fresh 17% Activated | 70% Fresh 30% Activated | 55% Fresh 45% Activated | 0% Fresh 100% Activated |
|---|---|---|---|---|---|---|
| 0 | 6.3 | 6.4 | 6.5 | 6.7 | 7.0 | 7.3 |
| 3 | 6.4 | 6.2 | 6.3 | 6.6 | 6.6 | 7.0 |
| 6 | 6.6 | 6.4 | 6.4 | 6.7 | 6.7 | 6.8 |
| 10 | 6.6 | 6.5 | 6.5 | 6.7 | 6.6 | 6.6 |
| 13 | 7.0 | 6.9 | 6.8 | 7.0 | 6.9 | 6.6 |
| 20 | 7.2 | 7.2 | 7.2 | 7.2 | 7.4 | 7.0 |
| 27 | 7.5 | 7.4 | 7.4 | 7.6 | 7.5 | 7.2 |
| 33 | 7.6 | 7.4 | 7.5 | 7.5 | 7.5 | 7.3 |
| 40 | 7.3 | 7.5 | 7.5 | 7.3 | 7.3 | 7.4 |
| 55 | 7.5 | 7.6 | 7.6 | 7.6 | 7.5 | 7.3 |
| 68 | 7.5 | 7.4 | 7.5 | 7.3 | 7.4 | 7.2 |
| 75 | 7.3 | 7.3 | 7.5 | 7.3 | 7.3 | 7.3 |
| 82 | 7.3 | 7.4 | 7.5 | 7.3 | 7.3 | 7.3 |
| 89 | 7.6 | 7.5 | 7.5 | 7.3 | 7.3 | 7.3 |
| 100 | 7.4 | 7.4 | 7.3 | 7.3 | 7.3 | 7.3 |

The activated sludge started at pH 7.3. It dropped to 6.6 in 10 days and then gradually rose to pH 7.0 above which point it remained for the rest of the digestion period. The mixtures of fresh solids and activated sludge started between these two initial values of 6.3 and 7.3. They dropped

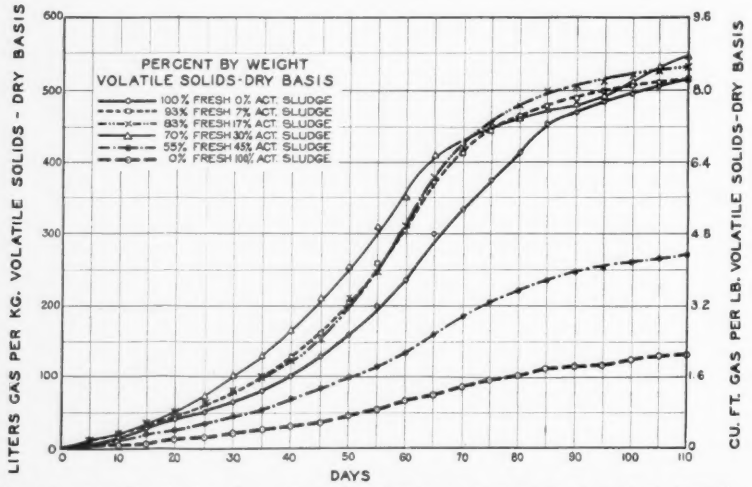



FIG. 6.—Gas Production from Unseeded Mixtures of Fresh and Activated Sludge at 15° C.

slightly and then rose in a manner similar to the fresh solids. These values are typical of a large number of samples and indicate that under normal conditions pH control is not necessary for the sludge obtained from the Des Plaines River Treatment Plant. A few samples which were limed did not show any marked improvement.

In general, the results from the 15° C. series, as presented in Figure 6, are similar to those obtained at 25° except for the great difference in the rate of digestion. At the lower temperature, the three mixtures containing 93%, 83% and 70% fresh solids digested somewhat more rapidly than the 100% fresh solids sample. This was also true of the 70% and 55% samples at 25° C., although the total amounts of gas formed were less than obtained from the 100% fresh solids sample. At 25° C., the digestion was complete in about half the time necessary at 15° C.

Table IV shows the maximum rate of gas production and the day upon which it was obtained. As shown by Imhoff,[13] and Fair and Carlson,[15] the highest rates are not obtained with fresh solids alone but with mixtures of fresh solids and activated sludge. Assuming that these maximum rates could be maintained, the digestion period would be materially shortened as indicated in Table IV.

TABLE IV

MAXIMUM RATES OF GAS PRODUCTION

| Mixture | Cu. Ft. per Lb. Volatile Solids per Day | | | | Calculated Period of Digestion at Maximum Rate—days | |
|---|---|---|---|---|---|---|
| | 15° C. | | 25° C. | | 15° C. | 25° C. |
| | Days | Gas | Days | Gas | | |
| 100% Fresh 0% Activated | 65 | 0.19 | 35 | 0.31 | 41 | 25 |
| 93% Fresh 7% Activated | 65 | 0.211 | 34 | 0.31 | 27 | 26 |
| 83% Fresh 17% Activated | 62 | 0.211 | 35 | 0.307 | 28 | 26 |
| 70% Fresh 30% Activated | 63 | 0.19 | 25 | 0.371 | 43 | 19 |
| 55% Fresh 45% Activated | 67 | 0.082 | 23 | 0.31 | 49 | 18 |
| 0% Fresh 100% Activated | 62 | 0.042 | 26 | 0.182 | 46 | 21 |

*Seeded Mixtures.*—Another series of sludges was set up at 20° and at 37° C. as described below:

100% Fresh solids
100% Fresh solids seeded
100% Activated sludge
100% Activated sludge seeded

The seeding was done with 1 ripe to 2 fresh or activated on the basis of the volatile solids. As may be seen from the curve in Figures 7 and 8,

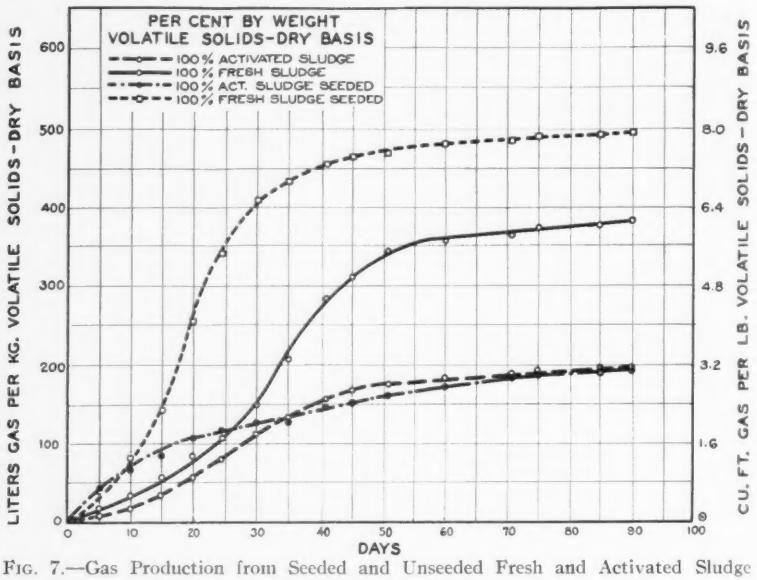

PER CENT BY WEIGHT
VOLATILE SOLIDS-DRY BASIS
100% ACTIVATED SLUDGE
100% FRESH SLUDGE
100% ACT. SLUDGE SEEDED
100% FRESH SLUDGE SEEDED
LITERS GAS PER KG. VOLATILE SOLIDS-DRY BASIS
CU. FT. GAS PER LB. VOLATILE SOLIDS-DRY BASIS
DAYS

FIG. 7.—Gas Production from Seeded and Unseeded Fresh and Activated Sludge at 20° C.

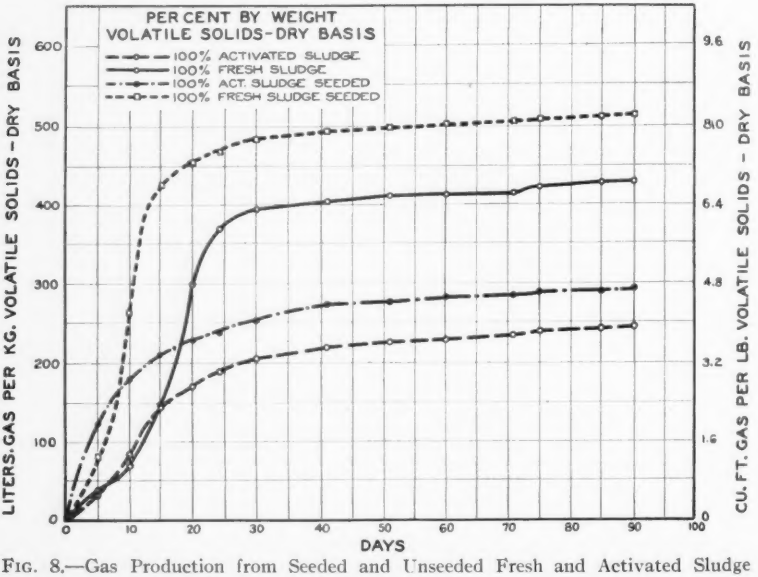

PER CENT BY WEIGHT
VOLATILE SOLIDS-DRY BASIS
100% ACTIVATED SLUDGE
100% FRESH SLUDGE
100% ACT. SLUDGE SEEDED
100% FRESH SLUDGE SEEDED
LITERS GAS PER KG. VOLATILE SOLIDS-DRY BASIS
CU. FT. GAS PER LB. VOLATILE SOLIDS-DRY BASIS
DAYS

FIG. 8.—Gas Production from Seeded and Unseeded Fresh and Activated Sludge at 37° C.

increase in temperature and seeding greatly shorten the time required for digestion. This seems particularly true of the fresh solids sample. The digestion period was shortened about twenty days by the increase in temperature and about ten days by the seeding. Thus the seeded fresh solids at 37° C. digested in about 20 days whereas the unseeded fresh solids at 20° C. digested in about 50 days. The effect of seeding and temperature was not so apparent with the activated sludge although the gas produced per unit of fresh volatile solids was greater at the higher temperature and in the seeded sample. The fact that more gas per kilogram of fresh organic solids is produced by the seeded material is partially accounted for by the gas given off from the volatile solids in the ripe sludge. This was not taken into account in the calculations.

**Comparison of Results.**—Table V summarizes for the different temperatures the gas formed per unit of fresh volatile solids at the time the sludge was ready for drawing. This time was determined by the flattening in the slope of the gas curve. Although the table is made up of two series it is evident that the time required for digestion decreases with increase in temperature. The greatest decrease in time required occurred between 15° and 20° C.

TABLE V

GAS PRODUCED AT TIME FOR DRAWING SLUDGE

| | Cu. Ft. per Lb. Initial Volatile Solids | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 15° C. | | 20° C. | | 25° C. | | 37° C. | |
| Mixture | Days | Gas | Days | Gas | Days | Gas | Days | Gas |
| 100% Fresh | | | | | | | | |
| 0% Activated | 85 | 7.3 | 54 | 5.6 | 55 | 8.4 | 30 | 6.7 |
| 100% Fresh | | | | | | | | |
| Seeded | | | 40 | 7.3 | | | 30 | 7.6 |
| 93% Fresh | | | | | | | | |
| 7% Activated | 75 | 7.12 | | | 50 | 8.15 | | |
| 83% Fresh | | | | | | | | |
| 17% Activated | 85 | 8.0 | | | 50 | 7.85 | | |
| 70% Fresh | | | | | | | | |
| 30% Activated | 70 | 6.75 | | | 40 | 6.87 | | |
| 55% Fresh | | | | | | | | |
| 45% Activated | 90 | 3.92 | | | 30 | 5.06 | | |
| 0% Fresh | | | | | | | | |
| 100% Activated | 85 | 1.76 | 40 | 2.5 | 40 | 3.84 | 30 | 3.36 |
| 100% Activated | | | | | | | | |
| Seeded | | | 20 | 1.72 | | | 30 | 4.13 |

There was a great difference in yield of gas from activated sludge and from fresh solids, either seeded or unseeded. In general the production of gas decreased as the amount of activated sludge increased. This difference grew less as the temperature increased but even at 37° there was only a little more than half as much gas produced from the seeded activated sludge as from the seeded fresh solids.

## PLANT INSTALLATIONS

**Plainfield, New Jersey.**[6]—Some preliminary studies on sludge digestion and gas production, covering a period of about 6 months from Oct., 1925, to April, 1926, were made at Plainfield, N. J., in a square earthen tank provided with a wooden floating cover. The effective capacity of this tank was 25,000 cubic feet. The temperature in the tank was initially 68° F., and gradually dropped to 50° F. by the middle of February, 1926. Below 60° F. the quantity of gas was too low to be measured.

About 1.60 cubic feet of gas per pound of volatile matter was obtained according to meter measurements, but due to cracks in the cover and along the edges, through which gas escaped, the measured gas was only an unknown proportion of the total production. Fresh solids from an Imhoff tank were added every two or three days, but the digestion tank became filled and further addition was stopped, first for a period of one month and later for six weeks.

One pound of lime for 390 pounds of solids added was required to maintain a pH of 7.3.

Two 16-sided concrete separate digestion tanks[18] having an effective capacity of 40,000 cubic feet and provided with wooden floating covers and heating systems were built in the spring of 1926. These tanks were operated on a 40-day digestion schedule at a temperature of 68° F. and with 7.3 as the average pH value. Daily additions of 1000 cubic feet of sludge were maintained. The amount of gas produced in these tanks has not been reported.

**New Castle, Pennsylvania.**[17]—The Imhoff tanks at New Castle, Pa., are provided with concrete covers for gas collection over the gas vents. The estimated population now tributary to the plant is 50,000. The average sewage flow is 4.82 million gallons per day.

Difficulty, first encountered by acid sludge, has been corrected by liming, but the latest available results do not indicate that the ultimate gas production has been attained.

The gas evolved during the first five months averaged only 50 to 100 cubic feet per day. Tests during April, 1927, showed 50 per cent $CO_2$ in the gas, and an acid reaction of the sludge of pH 5.2 to 6.8 was indicative of unfavorable digestion. Addition of lime to about 77,000 cubic feet of sludge was started May 7, 1927, and continued until Sept. 7, 1927. During this period a total of 30 tons of lime was added, and the sludge was re-circulated with a pump before a sludge reaction of pH 7.6 was obtained.

With excessive liming the gas production gradually increased to a measured maximum of 15,000 cubic feet per day in September, 1927. Accounting for a number of unavoidable leaks, it is estimated that the

actual gas produced was 25,000 cubic feet per day. Since liming the carbon dioxide content of the gas has fallen off to 14 per cent.

**Calumet Treatment Works.**—An Imhoff tank with provisions for collection and measurement of the gas evolved has been operated at the Calumet Treatment Works of the Sanitary District of Chicago, since Feb., 1926. Excepting a shut-down of the plant for repairs on the interceptor, from May to July, 1928, inclusive, operation for the entire period has been continuous. The tank had very little sludge in storage when put in operation for gas collecting, consequently it did not function normally until later in the summer. Therefore the period from September, 1926, to August, 1927, inclusive, has been selected to represent a typical year. The average flow of sewage through this tank was 1,400,000 gallons per day and the contributing population was 4400 people. The storage capacity for the sludge was 2.3 cubic feet per capita, which gives a storage period of about 5 months. The Calumet sewage contains 116 p. p. m. suspended matter of which 55% is volatile. In Table VI are shown the average operating data and analytical results pertaining to gas production as found for a period of 1 year.

Table VI

Data on Gas Collection

Imhoff Tank Calumet Treatment Works

Average Results for 1 Year

| | |
|---|---|
| Volatile solids removed—parts per million | 37 |
| Volatile solids removed—pounds per day | 430 |
| Gas produced—cubic feet per day | 1924 |
| Gas produced—cubic feet per lb. volatile matter added | 4.5 |
| Gas produced—cubic feet per capita per day | 0.44 |
| Composition of gas in per cent—methane | 76.6 |
| Composition of gas in per cent—carbon dioxide | 14.7 |
| Composition of gas in per cent—nitrogen | 8.2 |
| Composition of gas in per cent—oxygen | 0.5 |
| Heating value of gas in B. t. u. | 780 |
| Weight of 1 cubic foot of gas—pounds | 0.054 |
| Gas produced by weight from volatile matter added—per cent | 24.3 |

The tank was operated without heat or pH control. The pH reaction of the sludge was determined a number of times each month and found to vary from 6.3 to 7.0. The gas produced fluctuated over a wide range from day to day and although there was an evident correlation between gas production and temperature, over a seasonal range, the daily fluctuations cannot be accounted for by the temperature changes. It was found that sludge drawing retarded the gas production for several days, followed by very active production until normal conditions were again restored. Figure 9 shows the daily gas production for a typical winter and summer month. The monthly averages of daily production, however, followed

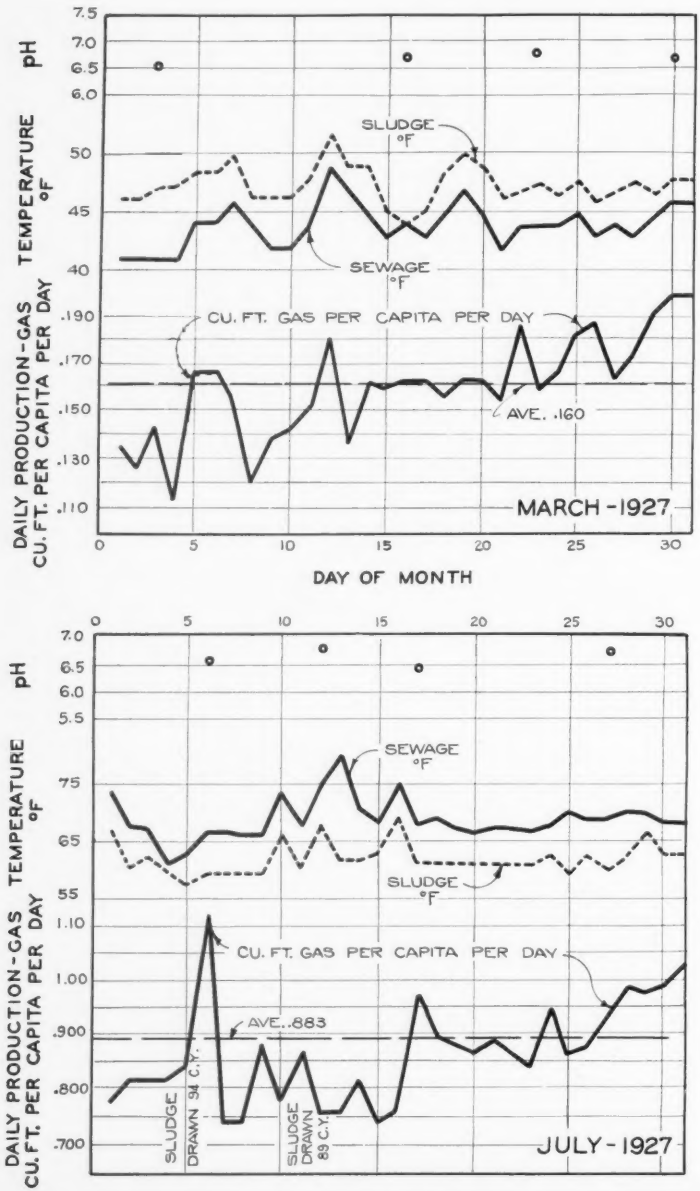



FIG. 9.—Daily Gas Production from Imhoff Tank, Calumet Sewage Treatment Works for March and July, 1927.

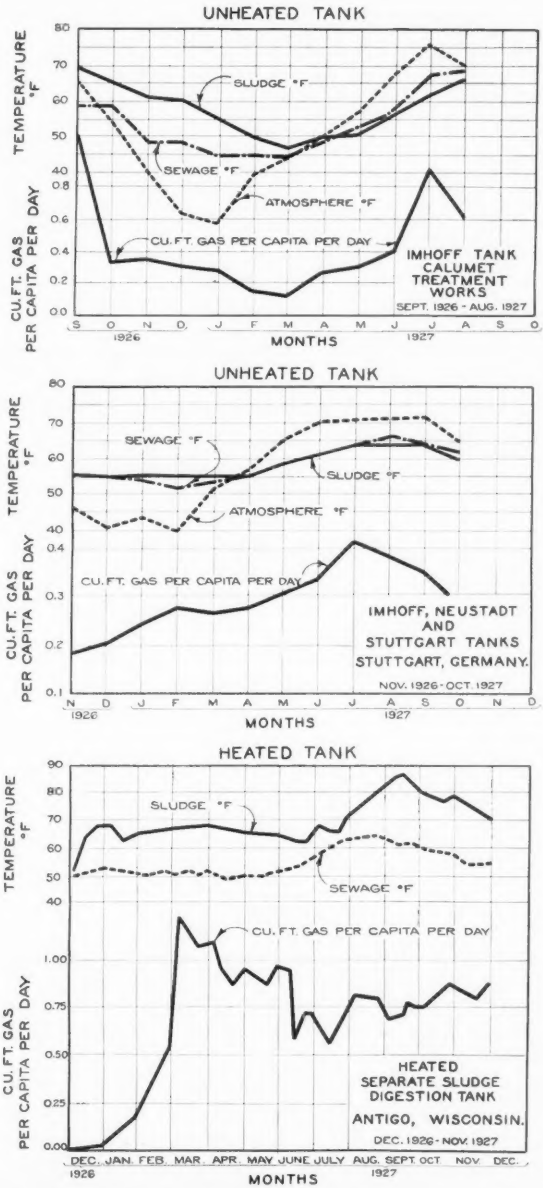



FIG. 10.—Gas Production from Settled Solids for 1 Year, in Heated and Unheated Tanks.

seasonal temperatures closely. It was found that the gas produced during the maximum month was 2.52 times and the maximum day was 3.3 times the average daily production for the year. Table VII and Figure 10 show the monthly averages of gas production and temperatures.

TABLE VII

GAS PRODUCTION

Calumet Treatment Works

| Month 1926–27 | Rate of Gas Cu. Ft. per Day | Production Ratio to Yearly Ave. | Max. Day Cu. Ft. | Min. Day Cu. Ft. | Temperature, Degrees F. Air | Sewage | Sludge |
|---|---|---|---|---|---|---|---|
| Sept. | 4840 | 2.52 | 6400 | 3300 | 67 | 58 | 70 |
| Oct. | 1495 | 0.78 | 2300 | 1000 | 54 | 58 | 66 |
| Nov. | 1607 | 0.84 | 2000 | 900 | 39 | 48 | 62 |
| Dec. | 1390 | 0.73 | 1700 | 500 | 28 | 48 | 61 |
| Jan. | 1375 | 0.72 | 1700 | 600 | 26 | 44 | 56 |
| Feb. | 804 | 0.42 | 1200 | 150 | 38 | 45 | 51 |
| March | 706 | 0.37 | 860 | 500 | 44 | 44 | 47 |
| Apr. | 1205 | 0.63 | 1700 | 800 | 51 | 48 | 48 |
| May | 1221 | 0.64 | 1800 | 500 | 58 | 53 | 52 |
| June | 1815 | 0.94 | 3400 | 1000 | 68 | 58 | 58 |
| July | 3884 | 2.02 | 5100 | 3300 | 77 | 69 | 62 |
| Aug. | 2749 | 1.43 | 4600 | 440 | 70 | 69 | 67 |
| Year—Ave. | 1924 | 1.00 | | | 52 | 54 | 58 |

Population tributary to tank—4400

Ave. gas—per capita per day—0.44 cu. ft.

4.50 cubic feet of gas per pound of volatile matter added.

**Des Plaines Testing Station.**—The sludge from a preliminary settling tank at the Des Plaines Testing Station of the Sanitary District of Chicago, operating on a 2-hour detention period, and the activated sludge from a pre-aeration unit for partial activated sludge treatment of sewage applied to a sprinkling filter, were digested in a wooden tank 20 ft. in diameter and 12 ft. deep, with a capacity of 3200 cubic feet. The preliminary settling tank and the digestion tank were equipped with Dorr clarifier apparatus. The digestion tank was insulated with a 12-in. layer of sawdust and provided with facilities for heating the sludge.

Operation of the testing station was begun in August, 1927. Since there was no activated sludge available at the start, the digestion tank was operated on fresh solids until November, 1927. The sewage treated at the testing station contained about 150 parts per million suspended matter of which 75 per cent was volatile.

The digestion tank was maintained at an average temperature of 73.3° F. for the year Nov., 1927, to Oct., 1928, inclusive, by passing hot water through the coils in the tanks.

Favorable digestion was obtained without pH control of the sludge. The pH of the tank liquor averaged 7.3. During the year 12,303 pounds

of fresh solids and 5873 pounds of activated sludge solids were added to the digestion tank. The gas produced per pound of volatile matter added was 8.35 cubic feet. In computing the gas on the basis of volatile solids for the year, the volatile matter in the tank still undergoing gasification at the beginning and end of the period was taken into consideration.

Based on the quantities of fresh and activated sludge added to the tank, the digestion period was about 6 months, which is about 3 times the minimum period that should be necessary for practically complete gasification at a temperature of 73° F.

Table VIII shows the monthly results of solids added and gas produced in the digestion tank.

TABLE VIII

GAS PRODUCTION

Mixture of Fresh and Activated Sludge

Des Plaines Testing Station

| Month 1927 | Lbs. Volatile Solids Added | | | Lbs. Volatile Solids Added Cumulative | Gas Produced Cu. Ft. per Mo. | Gas Produced Cumulative | Cu. Ft. Gas per Lb. Volatile Solids Cumulative | Temperature of Sludge in Tank Degrees F. |
|---|---|---|---|---|---|---|---|---|
| | Fresh | Activated | Total | | | | | |
| | 1135* | | | 1,135* | | | | |
| Nov. | 720 | 74 | 794 | 1,929 | 7,960 | 7,960 | 4.1 | 62.3 |
| Dec. | 258 | 153 | 411 | 2,340 | 5,510 | 13,470 | 5.7 | 72.0 |
| Jan. | 1340 | 96 | 1436 | 3,776 | 13,780 | 27,250 | 7.3 | 75.5 |
| Feb. | 922 | 114 | 1036 | 4,812 | 10,500 | 37,750 | 7.8 | 76.4 |
| Mar. | 1872 | 380 | 2252 | 7,064 | 22,234 | 59,984 | 8.5 | 75.6 |
| April | 752 | 699 | 1451 | 8,515 | 10,786 | 70,770 | 8.3 | 66.6 |
| May | 1166 | 572 | 1738 | 10,253 | 21,914 | 92,684 | 9.1 | 69.2 |
| June | 1039 | 245 | 1284 | 11,537 | 10,329 | 103,013 | 8.9 | 72.4 |
| July | 373 | 524 | 897 | 12,434 | 3,875 | 106,888 | 8.6 | 77.8 |
| Aug. | 1113 | 1125 | 2238 | 14,672 | 11,510 | 118,398 | 8.1 | 82.0 |
| Sept. | 934 | 934 | 1868 | 16,540 | 14,972 | 133,370 | 7.2 | 77.4 |
| Oct. | 679 | 957 | 1636 | 18,176 | 11,782 | 145,152 | 8.0 | 75.8 |
| Total | 12,303 | 5873 | −816* | | | | | |
| | | | 18,196 | | | | Ave. | 73.3 |

* Estimated undigested solids in tank.

Cubic feet of gas produced for 12 months $\frac{145,152}{17,358}$ = 8.35 cubic feet of gas per pound of volatile matter added.

Pounds of solids added during year (corrected for gas producing solids in tank at beginning and end of period).

The gas yield per pound of volatile solids added was less in April, July, August, September, and October, 1928, when increased proportions of activated volatile solids, as compared with fresh solids, were added to the digestion tank. The lower gas yield for April can hardly be attributed to the lower temperature, since in May with only a 3.6° F. increase in temperature and 20 per cent increase in volatile solids, but a higher ratio

of fresh to activated, the quantity of gas produced was double the April production. This is generally in accord with results obtained in laboratory tests for similar proportions of fresh and activated sludge. It appears that for optimum gas production the volatile matter in the activated sludge added should not exceed 30 per cent of the total volatile matter.

**Stuttgart, Germany.**[20]—The sewage treatment plant at Stuttgart, Germany, consists of Imhoff, Neustadt and Stuttgart tanks for clarification and digestion of sludge. The plant has a tributary population of 350,000 people and treats an average flow of about 23 million gallons of sewage per day. In 1923 some experiments were conducted during which 0.28 to 0.35 cubic ft. of gas per capita per day was collected. The gas was composed of 75.5 per cent methane, 14.0 per cent carbon dioxide, 4.8 per cent hydrogen and 4.7 per cent nitrogen. The heating value was 850 B. t. u. per cubic foot. Based on the experimental results obtained, provisions were made for collecting the gas from the entire plant.

The total gas produced per year from the 3 types of tanks amounted to an average of 100,000 cubic feet per day, equivalent to 0.29 cubic foot per capita per day. The monthly averages of daily gas production varied from a minimum of 59 per cent of the year's average in November to a maximum of 132 per cent in July. Figure 10 is a curve showing the daily gas produced and temperatures of atmosphere, sewage and sludge for the year by months. It is evident that the seasonal range of temperatures at the Stuttgart plant are not as great as at the Calumet plant, and therefore the Stuttgart results do not show the wide range of gas production found in the Calumet tests.

The gas recovered at Stuttgart, after being purified to remove hydrogen sulfide and other impurities, is sold to the local gas company where it is mixed with coal gas for commercial use. The gas is sold at a profit, which, after deducting the annual cost of operating the gas collecting equipment, will pay for the original construction cost of this equipment in two years. It has been proposed that provisions be made for heating the sludge in the Neustadt tanks in order to increase the rate of gas production.

**Antigo, Wisconsin.**[21]—At Antigo, Wisconsin, gas is collected from a heated separate sludge digestion tank. The average sewage flow based on a week's test run is about 600,000 gallons per day. The contributing population is estimated to be 5600. A description of the plant together with detailed data on gas production for a period of 51 weeks are given in "Public Works" for March and April, 1928, by Anthony J. Fischer and Frank K. Quimby. The digestion tank has a capacity of 5 cubic feet per capita for sludge storage, providing the excessively long storage period of $2\frac{1}{2}$ years. The sludge in the tank was maintained at a temperature of 68° F. in the winter and in the neighborhood of 80° F. in the summer.

The gas produced, as given for a period of 51 weeks, amounted to an

average of 3710 cubic feet per day or 0.66 cubic foot per capita per day. More recent results indicate a production of 0.80 cubic foot per capita per day. It is of importance to note that the gas evolved per capita is based on the human population without accounting for gas producing material in the cheese factory wastes discharged to the plant until August 1, 1928.

For the period ending Aug. 31, 1927, the average daily gas production was 11.5 cubic feet per pound of volatile solids added, or 15.4 cubic feet per pound of volatile matter decomposed. These results would seem to indicate that about 94 per cent of the volatile matter decomposed was gasified. The suspended solids added were estimated at 428 pounds per day, of which 72 per cent is volatile matter. The determinations of suspended solids upon which this estimate was based covered only a short period during the investigations, consequently there is some doubt as to whether the results were representative for the entire year's operations. The Antigo results of gas evolved, expressed in cubic feet per pound of volatile matter, are higher than have been obtained in most of the laboratory tests or working installations. A very complete reduction of volatile solids was obtained, averaging 75 per cent.

**Decatur, Illinois.**[4]—Gas has been collected from the Imhoff tanks at Decatur, Illinois, since October 15, 1925. About half the gas-vent area was capped and gas was collected from October 15, 1925, until June 4, 1926. Permanent concrete covers were then installed over all of the tanks in August, 1926. The Decatur sewage is a mixture of 5,000,000 gallons per day of sewage from a population of 40,000 and 5,000,000 gallons of waste from the Staley Corn Products Manufacturing Company. The mixture as received at the plant is about five times the strength of normal domestic sewage. The temperature of the sewage at the plant ranges from a minimum of 68° F. in winter to a maximum of 104° F. in summer.

The daily gas production varied directly as the temperature in the tank, from 30,000 cubic feet at 60° F. to 125,000 cubic feet at 75° F. The total gas produced, however, averaged about 100,000 to 125,000 cubic feet per day, with occasional minimum of 30,000 cubic feet per day when the starch works were shut down or when sewage temperature was brought down to 50° or 60° F. by melting snow.

The reaction of sludge in the Imhoff tanks was 6.8 to 7.0 pH. At a pH of 6.5 difficulty was encountered due to foaming.

The average composition of the gas produced from the Imhoff tanks was 60 per cent methane, 22 per cent carbon dioxide and 6 per cent nitrogen. It had a heating value of 700 B. t. u. per cubic foot.

Owing to the large amount of digestible volatile matter present in the Decatur sewage, due to corn products and other industrial wastes, the gas evolved cannot be properly expressed on a per capita basis. There are no published data on the volatile matter in the settled solids or di-

gested sludge from the Imhoff tanks, but the results of some bottle experiments in the laboratory furnish a basis for the calculation of gas production as related to initial volatile solids. The samples were initially seeded with ripe sludge and daily increments of fresh solids were added for 90 days to approximate conditions in the existing Imhoff tanks. The gas yield per pound of volatile matter added, based on the last 50 days or the test after equilibrium of sludge digestion was established, is shown in Table IX.

TABLE IX

| Temperature, ° F. | Cubic Feet of Gas per Pound Volatile Matter Added |
|---|---|
| 52 | 6.4 |
| 66 | 8.0 |
| 88 | 9.2 |
| 95 | 9.0 |

**Essen-Rellinghausen, Germany.** Following experimental work at the Essen-Rellinghausen Plant, Imhoff[13] reported in 1925 that 0.28 cubic foot of gas per capita per day was evolved in the digestion of fresh solids from a preliminary settling tank. When this was mixed with the excess sludge from an activated sludge unit, following the preliminary settling tank, the total gas produced was 0.56 cubic foot per capita. Imhoff gives curves to show the rate of gas production for various mixtures. The following table is taken off the curves to show the volume of gas produced per pound of organic matter in the original mixture, when incubated at 17° C. for periods of 30 to 70 days.

CUBIC FEET OF GAS PER POUND OF ORGANIC MATTER AT 17° C.

| Mixture | 30 Days | 70 Days |
|---|---|---|
| 0.5 activated—0.5 fresh—1 digested | 3.6 | 4.0 |
| 1 activated—1 digested | 2.7 | 3.9 |
| 1 fresh—1 digested | 1.9 | 3.9 |
| Activated alone | 0.1 | 0.4 |

The Essen-Rellinghausen Plant[22] was put in operation in December, 1925. It consists of 6 Imhoff tanks, followed by activated sludge treatment with preliminary digestion of fresh and activated sludge in the Imhoff compartments. Part or all of the sludge is pumped from the Imhoff tanks into a supplementary heated sludge digestion tank for final digestion. The plant serves a population of 45,000 people and receives a dry-weather flow of 5.8 million gallons per day.

Imhoff[22] reports that prior to the operation of the activated sludge plant, the total gas produced from all sludge digestion compartments amounted to 0.21 cubic foot per capita per day. Upon addition of the activated sludge, a reduction in production of gas occurred, which may be attributed to the decrease in the digestion period. In order to speed up the digestion

rate, the application of heat to the secondary digestion tank was introduced. This resulted in a 10-fold increase in rate of gas production, according to Imhoff.[22]

In a more recent article by Fries,[23] the gas produced in the secondary digestion tank for 1927, since the introduction of heat, is reported.

The total capacity for sludge digestion was 1.15 cubic feet per capita, of which 0.75 cubic foot was in the Imhoff tanks and 0.40 cubic foot in the secondary sludge digestion tank. Sludge remained in the Imhoff tanks for a period of 11 days at an average temperature of 59° F. It was then removed to the separate digestion tank, which was maintained at a temperature of 68° F. by use of a part of the gas evolved. The digestion period of the secondary tank was 20 days. The quantity of gas produced was 2870 cubic feet per day, which according to Fries' figures was about three times the amount obtained before heating.

The low rate of gas produced in the digestion tank may perhaps be explained by loss of gas through leaky covers and concrete tanks and also by the possibility that not all sludge was transferred from the Imhoff tanks to the separate digestion tank.

**Essen-Frohnhausen, Germany.**—Some interesting results have been reported by Dr. Max Prüss,[24] sanitary engineer of the Emschergenossenschaft, concerning the effect of vertical circulation of sludge and insulation of digestion tanks, on the yield of gas from sewage sludge. The investigation was conducted at Frohnhausen, near Essen, on settled solids in a circular tank having a capacity of 17,650 cubic feet, with the sludge heated to a temperature of 77° F. The sludge was digested to a moisture content of 80 per cent first without, and later with, artificial circulation, and finally to complete digestion with artificial circulation. The sludge was circulated twice daily from bottom to top by means of a screw pump having a capacity of 150 gallons per minute.

The solids added to the tank amounted to 0.11 pound per capita per day, of which 70 per cent was volatile matter. Based on the reported weight of the gas of .063 pound per cubic foot, and 67 per cent digestion of volatile matter, 87 per cent of the volatile matter by weight was gasified. The comparative results for gas yield are shown in Table X.

TABLE X

GAS PRODUCED AT FROHNHAUSEN

| Condition | Cu. Ft. Gas per Capita per Day | Cu. Ft. Gas per Lb. Volatile Matter | Time of Digestion in Months |
|---|---|---|---|
| *Without* artificial rotation to 80% moisture | 0.35 | 4.55 | 2.00 |
| *With* artificial rotation to 80% moisture | 0.41 | 5.32 | 1.33 |
| *With* artificial rotation to complete digestion | 0.70 | 9.10 | 2.67 |

Dr. Prüss[24] further reports that at Essen-Nord 100 per cent increase in gas yield results from artificial circulation of sludge, and also that

the same amount of gas is produced in one-half the time required in quiescent sludge. Approximately 250,000 cu. ft. of sludge digestion capacity is now in operation in various plants in the Emscher District and elsewhere in Germany, in which Prüss'[24] ideas are being tested. Data from these plants should be of great interest.

## Other Installations

**European Cities.**—Gas from sewage sludge has been collected for several years at Birmingham, England.[25] Floating covers for one-third of the primary sludge digestion tanks were put in operation Sept. 29, 1927. Fresh sludge is digested in primary digestion tanks for a period of three months at Saltley and then removed to secondary digestion tanks for an additional period of two months.

The gas collected is used to run a 150 h. p. vertical gas engine, generating electricity for pumping sludge and other purposes. It is estimated that 44,000 cubic feet of gas per day will be produced from the covered unit. It is expected that another unit of the same size will be installed.

In the process of digestion 25 to 33 per cent of the dry solid matter is converted into gas, composed of 67 per cent methane, 30 per cent carbon dioxide, and 3 per cent nitrogen, which has a heating value of 625 B. t. u. per cu. ft.

Reinforced concrete covers, hemispherical in shape, have been installed for the collection of gas at Munich.[26] The tributary population to this plant is 500,000. It is expected to sell the gas to the city gas works.

A gas collector has been in operation at Zurich,[26] Switzerland, on one unit of the sludge digestion tanks since July, 1925. All of the units are designed for ultimately collecting all of the gas, which is estimated to be about 58,000 cubic feet per day from a population of 200,000. A treatment plant is in operation producing gas from a population of 13,000, at Parramatta, New South Wales,[26] Australia.

Gas from sewage sludge is also collected and utilized at a plant near Bristol, England, Brisbane, Australia, and Lithgow, Australia. The details of these installations are not available.

**American Cities.**—Some recent installations of gas-collecting equipment in American cities from which data are not yet available are Dayton, Ohio, Sioux Falls, South Dakota, and Storm Lake, Iowa. It is hoped that data from these places will be forthcoming in the near future.

## Discussion and Summary

The laboratory data and plant results in this country and in Germany demonstrate that sufficient gas of good heating qualities is evolved in the digestion of sewage sludge, whether in Imhoff or separate digestion tanks, to make its collection and use both feasible and practical.

The German results on yield of gas per capita and also per unit of settled sludge, based on results thus far available, appear to be lower than in the United States, if we except Prüss' results for heated, circulated sludge. The tanks at Stuttgart and experiments at Essen-Rellinghausen on settled sludge produced 0.29 cubic foot per capita per day as compared with 0.44 cubic foot per capita per day at Calumet.

The laboratory results reported by German investigators also show lower yields of gas per pound of volatile matter. In experimental work at Essen-Rellinghausen on mixtures of activated sludge and settled solids 0.56 cubic foot per capita of gas was produced. When the full-scale plant was put in operation only 0.21 cubic foot of gas per capita was obtained. Upon addition of activated sludge for digestion extremely low gas yields were obtained in the supplementary tank which were increased three times according to Fries and ten times according to Imhoff after heating was introduced. Fries' results cover a year's operation; Imhoff's probably a shorter period.

Prüss found from his experiments that, in a digestion tank heated to 77° F., sludge digested for two months without circulation produced 0.35 cubic foot per capita as compared with 0.41 cubic foot per capita for sludge digested for 1.33 months with circulation. By prolonging the digestion period to 2.67 months 0.70 cubic foot per capita was obtained with circulation of sludge.

Owing to the initial difficulties encountered at New Castle and Plainfield there are no results available from plants in this country with which to compare results from the Imhoff tank at Calumet and the heated separate sludge digestion tank at Antigo. At Calumet a gas yield of 4.5 cubic feet per pound of volatile matter added was obtained. At Antigo the gas yield of 11.5 cubic feet per pound of volatile matter in the settled solids is higher than has been obtained at any other plant. The more recent figure of 0.80 cubic foot of gas per capita per day would indicate that 94 per cent of the volatile matter formed gas. Whether such efficient results are typical for long digestion periods and digestion capacity of 5 cubic feet per capita, or whether the high yield as found is the result of insufficient data on volatile solids added, is a matter of great interest, which possibly requires further confirmation.

The Des Plaines digestion tank, operating on a mixture of fresh and activated sludge has demonstrated the need of proportioning the volatile and fresh solids in order to obtain the maximum yield of gas. The production of 8.35 cubic feet of gas per pound of volatile matter is probably higher than would be obtained if the digestion tank were worked to capacity. Diminished gas production results from mixtures containing more than 33 per cent volatile activated solids by weight.

A summary of the data on gas production for the installations discussed

in this paper is given in Table XI. The yield per pound of volatile matter in all cases is based upon the volatile or organic solids initially present in the settled solids.

TABLE XI

SUMMARY OF GAS PRODUCTION

| Plant | Nature of Solids | Population Treated | Sewage Flow-Gal. per Day | Gas Production: Cu. Ft. per Cap. per Day | Gas Production: Cu. Ft. per Lb. Volatile Matter | Remarks |
|---|---|---|---|---|---|---|
| Calumet | Settled sludge | 4,400 | 1,400,000 | 0.44 | 4.50 | Not heated |
| Stuttgart | Settled sludge | 350,000 | 23,000,000 | 0.29 | .. | Not heated |
| Essen-Rellinghausen | Settled sludge | Experimental plant | | 0.28 | .. | Not heated |
| Essen-Rellinghausen | Settled sludge and activated sludge | Experimental plant | | 0.56 | .. | Not heated |
| Essen-Rellinghausen | Settled sludge | 45,000 | 5,800,000 | 0.21 | .. | Not heated |
| Essen-Frohnhausen | Fresh solids | | | | | |
| | Without circulation | 22,000 | ..... | 0.35 | 4.55 | Heated |
| | With circulation—incomplete digestion | 33,000 | ..... | 0.41 | 5.32 | Heated |
| | With circulation—complete digestion | 22,000 | ..... | 0.71 | 9.10 | Heated |
| Des Plaines Testing Station | Settled and activated | .... | 134,000 | .. | 8.35 | Heated |
| Antigo | Settled sludge | 5,600 | 600,000 | 0.66 | 11.5 | Heated |

The effect of seeding on the digestion of fresh solids at 20° and 37° C. and activated sludge at 37° C. is shown by an increase in total yield of gas as well as by higher rates of gasification. At 20° C. the total gas produced and average rates of gasification are the same for the seeded and unseeded samples of activated sludge. In all cases a maximum rate of gas production was obtained sooner with seeded samples. Table XII compares gas produced in the Sanitary District of Chicago Laboratory from seeded and unseeded fresh and activated sludge.

TABLE XII

COMPARISON OF TOTAL GAS PRODUCED FROM SEEDED AND UNSEEDED SOLIDS

| Sample | Time Days | Cu. Ft. Gas Produced per Pound of Volatile Matter: 20° C. | 37° C. |
|---|---|---|---|
| Fresh | 90 | 6.1 | 6.9 |
| Fresh seeded | 90 | 8.0 | 8.3 |
| Activated | 90 | 3.1 | 3.9 |
| Activated seeded | 90 | 3.1 | 4.7 |

From Table XII it appears that at higher temperatures the yields of gas from seeded activated sludge and seeded fresh solids tend to approach each other. Fair and Carlson reported approximately equal values for yields of gas from seeded activated sludge and seeded fresh solids incubated at 37° C. This temperature was considerably above the maximum ever obtained in practice.

Laboratory tests indicate that lower total yield of gas results from mixtures containing more than 30 per cent by weight of volatile activated sludge.

A limited amount of laboratory data indicated that the gas produced under conditions of alternate pressure and vacuum was the same as that produced at atmospheric pressure. Another experiment indicated that the gas produced in 57 days under a continuous vacuum of 15 inches of mercury was the same as that obtained at atmospheric pressure.

The general conclusions from practically all studies of gas production are that:

(1) Optimum conditions for gas production occur when the pH of the sludge is between 6.5 and 7.6. The need for adjustment of hydrogen-ion concentration must be determined to meet local operating conditions.

(2) Optimum temperature for artificial heating of sludge is at 77° F.

(3) The average composition of gas produced at treatment plants operating on domestic sewage is about 75 per cent methane, 20 per cent carbon dioxide, and 5 per cent nitrogen and other gases.

(4) The heating value of gas produced from sewage is 700 to 800 B. t. u. per cubic foot.

## Acknowledgment

The Sanitary District work was carried out under the direction of Mr. Langdon Pearse, Sanitary Engineer and Dr. F. W. Mohlman, Chief Chemist. The authors wish to express their appreciation to Dr. Mohlman for aid in preparing manuscript, and to the various engineers and chemists who have carried on the experimental work at the treatment plants and in the laboratories.

## Bibliography

[1] W. Rudolfs, Report of Department of Sewage Disposal of the N. J. Agr. Expt. Station (1927), p. 284.

[2] W. Rudolfs, *Ind. Eng. Chem.*, **19,** 241 (Feb., 1927).

[3] H. G. Baity, Proceedings, N. J. Sewage Works Assn., (1926), p. 27.

[4] W. D. Hatfield, G. E. Symons and R. R. Mills, *Ind. Eng. Chem.*, **20,** 174 (Feb., 1928).

[5] K. Imhoff, *American City*, **38,** 124 (May, 1928).

[6] W. Rudolfs, *et al.*, Report of Sewage Substation of N. J. Agr. Expt. Station (1926), p. 412.

[7] G. M. Fair and C. L. Carlson, *Eng. News-Rec.*, **99,** 881 (Dec. 1, 1927).

[8] F. Sierp, *Tech. Gemeinde.*, **39,** 267 (Feb., 1927).

[9] M. Prüss, *Tech. Gemeinde.*, **30,** 70 (June, 1927).

[10] H. Blunk, *Gesundh. Ing.*, **48,** 37 (January, 1925).

[11] W. Rudolfs, Report of Sewage Substation of N. J. Agr. Expt. Station (1925), p. 89.

[12] Chester Cohen, *Eng. News-Rec.*, **101,** 319 (Aug. 30, 1928).

[13] K. Imhoff, *Eng. News-Rec.*, **94,** 936 (June 4, 1925).

[14] W. Rudolfs and P. J. A. Zeller, *PublicWorks*, **58,** 253 (July, 1927).

[15] G. M. Fair and C. L. Carlson, *J. Boston Soc. Civil Eng.*, **14,** 487 (Nov., 1927).

[16] W. Rudolfs, *et al.*, Report of Sewage Substation of N. J. Agr. Expt. Station (1925), p. 50.

[17] G. M. Fair and C. L. Carlson, *J. Boston Soc. Civil Eng.*, **14,** 82 (Feb., 1927).

[18] W. Rudolfs and P. J. A. Zeller, Report of Dept. of Sewage Disposal of the N. J. Agr. Expt. Station (1927), p. 264.

[19] W. Donaldson, Proceedings N. J. Sewage Works Assn. (1928), p. 26.

[20] W. Sohler, *Gesundh. Ing.*, **51,** 134 (March, 1928).

[21] A. J. Fischer and F. K. Quimby, *Public Works*, **59,** 97 and 134 (March and April, 1928).

[22] K. Imhoff, *Eng. News-Rec.*, **99,** 790 (Sept. 17, 1927).

[23] F. Fries, *Gesundh. Ing.*, **51,** 577 (Sept., 1928).

[24] M. Prüss, *Gesundh. Ing.*, **51,** 439 (July, 1928).

[25] F. C. Vokes and C. B. Townsend, *Abstract Public Works*, **59,** 47 (Feb., 1928).

[26] Fuller-McClintock, "Solving Sewage Problems," pp. 327–329, etc.

# The Nidus (Nest) Rack, a Modern Development of the Travis Colloider

BY A. M. BUSWELL[1] AND E. L. PEARSON[2]

## Need for Intermediate Method of Treatment of Sewage

Both activated sludge and sprinkling filters produce effluents of very high quality, often carrying less organic matter than the streams into which they are discharged. Settling tanks, on the other hand, remove only a third or less of the organic matter. There are many cases where an intermediate degree of purification would be satisfactory. Partial treatment with filters is impracticable, but partial treatment with activated sludge has been employed to relieve the load on trickling filters.

A device intermediate between activated sludge and trickling filters is also needed. In the filter the amount of active surface per cubic foot is low, while in activated sludge it is high. An activated-sludge plant of given capacity is from one-tenth to one-fifteenth as large as a tank and filter installation of like capacity. The operating costs of the former are high, as is also the construction cost of the latter. A device more compact and less costly to build than filters and not expensive to operate would find wide use. The colloiders of Travis, with laths placed in the sedimentation chamber on 6-inch to 9-inch centers, represented a step in the right direction; but the amount of surface was small and the accumulated growths became septic and redispersed. The lath filters of Black and Phelps (N. Y. Harbor Report, 1911, pp. 64–78) were subject to the same limitation. Many filters made of rather fine-grained material have been used in experimental and large-scale installations from time to time but have not come into general use because of the danger of clogging. Brushwood has frequently been employed. Favorable results were reported on a large brush filter in Toronto (*Eng. Rec.* 75:376). Richards and Weeks (*J. Soc. Chem. Ind.* 40:252R) have experimented with straw filters, and we are operating a small corn cob filter (*Eng. Contr.* 65:2). Woody vegetable material will decompose in time, and at present data are not available to determine whether the cost of replacement of cobs will offset the saving in cost of installation. A recent experiment with an aerated sand filter has been reported by Basiakine (Report of the Sewage Commission of Moscow, 1925).

Previous experiments led us to believe that the limited success of the Travis "colloiders," as his devices were called, was due to three factors. First, the small amount of surface afforded by these colloiders could not be expected to be very effective. Our experiments on activated sludge showed that in the aeration chamber the sludge particles presented a surface

[1,2] *Chief and Asst. Chemist, Illinois State Water Survey Division, Urbana, Illinois.*

of 500 square feet per cubic foot of tank volume. An increase in the amount of surface should increase the purification. The second factor which apparently limited the success of the Travis colloiders was the lack of any provision for the removal of the precipitated material from the contact surfaces after it had collected there. Failure to provide such arrangement was due, no doubt, to Travis' fixed opinion that bacteria had nothing to do with the purification process. When bacteria are taken into account, one would normally expect that the organic matter, once precipitated on the contact surfaces, would be subject to the attack of putrefying organisms which characteristically liquefy organic matter. Apparently, the material allowed to remain on the surface of the colloiders became septic and partly liquefied and was thereby redispersed in the liquid; thus the precipitation was largely offset. The third reason for the limited success of the Travis colloiders, namely, failure to maintain aerobic conditions, was also overlooked on account of a lack of recognition of biological principles. It is commonly known that organisms growing in large compact masses are aerobic, while anaerobic activities are essentially liquefying in their results. With a fresh, well-aerated sewage a considerable growth of colloid-precipitating organisms would appear on the colloiders, but with a slightly stale liquor such growth would not appear or would be very slight.

### Experiments at the Illinois State Water Survey

On the basis of this reasoning a rather long series of experiments (1920 to date) has been carried on in the laboratories and at the experimental plant of the Illinois State Water Survey to determine the possibility of using submerged surfaces for the removal of colloids from sewage. Small-scale experiments carried out in 5- to 10-gallon containers were first reported in 1923 (*Engineering News-Record*, 90: 835). An experiment on a larger scale was carried out from 1924 to 1926 by Dr. Shive (Ill. State Water Survey, *Bulletin* No. 25).

Briefly, equipment for this experiment consisted of a tank, 8 feet in diameter and 4 feet deep, in which were placed 8 screen-wire racks of triangular cross section so designed that, when stood on end within the circular tank, they filled the entire volume, except for a central octagonal well 18 inches in diameter, and 8 peripheral arcs. These racks were provided with handles so that they could be moved up and down in the liquid. This operation dislodged the accumulated bacterial growth and was necessary about twice a day. The area of the contact surfaces was approximately 24 square feet per cubic foot.

Sewage was introduced into the central well of this tank and was caused to circulate through the racks. During some of the runs circulation was brought about by means of a revolving propeller in the central well, and

in other runs by means of compressed air introduced through a Filtros plate at the bottom of this well. The results of these experiments indicated that submerged surfaces, when used in a ratio of surface to volume of 20 or more to 1, will remove 30 per cent of the non-settleable or *colloidal organic* matter from domestic sewage, provided (1) that the accumulated matter is removed from surfaces at frequent intervals and (2) that aerobic conditions are maintained. They also show that bio-precipitation occurs even though the oxygen supply is very low.

Subsequent to the work of Shive, experiments with contact surfaces have been continued by the State Water Survey, using tanks constructed to provide for more effective removal of sludge. The result of these experiments confirm the conclusions drawn from Shive's experiments. The data are summarized in Table I, showing 41 per cent decrease in the biochemical oxygen demand. If the decrease in B. O. D. due to plain sedimentation is considered as 30 per cent, the contact surfaces may be said to have increased the efficiency of the installation by 30 per cent.

TABLE I

DATA ON THE OPERATION OF LATH NIDUS TANK FROM JANUARY 2 TO APRIL 19, 1927

| Temperature | Approximate Flow in Gallons per Minute Maximum | Median | Minimum | Average Detention Period 2 Hours |
|---|---|---|---|---|
| 12–15° C. | 16 | 13.6 | 9.4 | Volume = 2040 gallons |

Composite Samples January 14 to April 19, 1927

| | Influent P. p. m. | Effluent P. p. m. | Per Cent Removal |
|---|---|---|---|
| *Settling solids | 101.4 | 49.2 | 51.4 |
| Oxygen consumed | 53.6 | 39.6 | 26.4 |
| B. O. D. | 112 | 65.6 | 41.2 |

Grab Samples

| | Influent P. p. m. | Effluent P. p. m. | Per Cent Removal |
|---|---|---|---|
| B. O. D. 6 a.m. | | | |
| January 15, 1927, to April 19, 1927 | 22.7 | 16.8 | 26 |
| B. O. D. 8:30 a.m. | | | |
| January 14, 1927, to February 7, 1927 | 214 | 148 | 31 |
| B. O. D. 11 a.m. | | | |
| February 8, 1927, to March 15, 1927 | 213 | 119 | 44 |

* Estimated by weight.

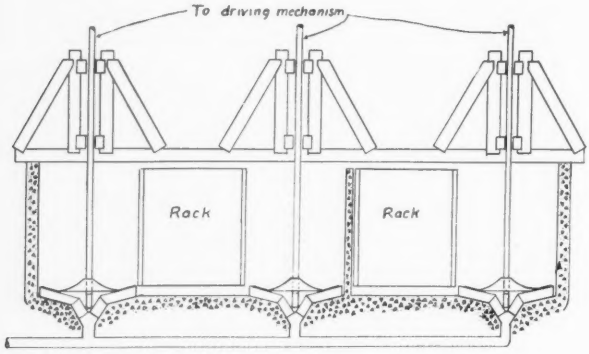
For the last year a Nidus tank arranged as shown in Figure 1 has been in operation. This tank is constructed to allow for the contact surface treatment in two stages separated by intermediate sedimentation. The contact surface in this experiment was provided by mats woven from veneer or basket strips. The construction of these mats is described later.

The detention periods at different times of the day and in the successive steps of the treatment are shown in Table II.

TABLE II
HOURS RETENTION

| | Sedimentation | Aeration | Sedimentation | Aeration | Sedimentation | Total | Rate of Flow G. P. M. |
|---|---|---|---|---|---|---|---|
| 6 a.m. | 0.53 | 0.43 | 0.53 | 0.50 | 0.32 | 2.31 | 18.23 |
| 2 p.m. | 0.61 | 0.50 | 0.61 | 0.58 | 0.37 | 2.67 | 15.80 |
| 10 p.m. | 0.93 | 0.76 | 0.93 | 0.88 | 0.56 | 4.06 | 10.38 |

Air was introduced through perforated pipes placed underneath the racks. The amount used was 0.1 to 0.2 cubic foot per gallon under the first rack and 0.2 to 0.1 cubic foot per gallon under the second. The detailed results did not show an improvement of the effluent when the higher amount of air was used.




Section of Nidus Tank

FIG. 1.

TABLE III
DATA ON THE OPERATION OF TWO-STAGE VENEER NIDUS TANK
June–July, 1928

| | Influent | Effluent | Per Cent Removal |
|---|---|---|---|
| Settleable solids | 169.0 | 49.0 | 71.0 |
| Oxygen consumed | 47.8 | 39.0 | 18.4 |
| Organic nitrogen | 18.8 | 14.9 | 20.7 |
| B. O. D. | 323.0 | 193.0 | 40.2 |

TABLE IV
DATA ON THE OPERATION OF TWO-STAGE VENEER NIDUS TANK
Aug.–Nov., 1928

| | Influent | Effluent 1st rack | Per Cent Removal | Final Effluent | Per Cent Removal |
|---|---|---|---|---|---|
| Settleable solids | 137.0 | 49.7 | 63.7 | 36.8 | 73.0 |
| Oxygen consumed | 51.5 | 42.7 | 17.1 | 40.9 | 20.6 |
| Organic nitrogen | 17.4 | 15.1 | 13.2 | 13.1 | 24.7 |
| B. O. D. | 270.0 | 178.0 | 34.1 | 161.0 | 40.4 |

The tables (III and IV) show the effect of this type of treatment. In Table III are given the average analyses of composite samples of influent and final effluent over an eight-week period. Analyses of the intermediate liquor showing the effect of the first rack were omitted because of sampling difficulties.

In general these data show the suitability of veneer mats as a surface material and at the same time confirm previous observations to the effect that the purification obtained by this process is 30 to 50 per cent greater than the percentage reduction that can be obtained by plain sedimentation for a corresponding detention period. The data (Table IV) do not appear to justify two-stage treatment in the form in which it was carried out in this experiment. Further experimentation with different ratios of sedimentation to aeration are contemplated.

## German Installations

This discussion would not be complete without a mention of two articles by Dr. Karl Imhoff (*Engineering News-Record*, December 9 and 23, 1926, and October 18, 1928) which describe ten large scale installations of similar devices (Tauchkörper) in Germany.

In the "Tauchkörper" installations the middle third of the sedimentation chamber of an Imhoff tank contains a rack made up with lath, underneath which an oscillating perforated pipe introduces compressed air. The intermittent aeration removes the growth accumulations, which settle in the last third of the chamber. Using 0.1 cubic foot per gallon, Imhoff obtains about the same degree of purification as is obtained in our experiments.

## Notes on the Construction of Nidus Racks

**Surface Material.**—Our experience indicates that any type or kind of surface may be used for supporting the biological growths, with the possible exception of very smooth glassy surfaces, or irregular material like coke, which becomes clogged. Strings of cotton or hemp, copper gauze, galvanized iron gauze, as well as lath and brushwood, have been used with success. Strings have not proved durable in small-scale experiments; metal cloth which will not corrode (copper or monel metal) is expensive; brushwood is not a common article of commerce in this country as it is in Europe; lath is satisfactory but more bulky (smaller ratio of surface to volume) than the other materials.

Veneer or basket wood may be had in strips of almost any desired length, width and thickness. Veneer strips may be woven into mats, these mats fastened into a frame with any desired spacing, and a rack thus constructed which has a large surface area and a relatively small displacement in water.

Such racks have been in use in our experiments for nearly a year. The

results from the standpoint of purification are equal to or a little better than those obtained with lath racks. The veneer racks are lighter and more easily handled. They become water-soaked more quickly than lath racks so they do not have to be weighted down.

Strips 1 x $^1/_{13}$ x 72 in. have been used in our experiments. This size was chosen arbitrarily, and found satisfactory. The construction of the mats is shown in Figure 2.

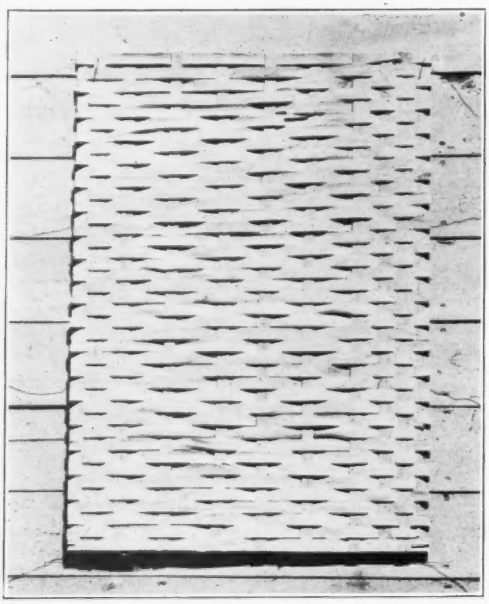


FIG. 2.—Photograph of Veneer Mat for Nidus Rack.

To date, no deterioration of the veneer has been observed. Iron wires used to fasten the mats in the frame rusted out in about nine months. Copper wire is now used for this purpose. No data on the life of copper wire is available, but experience with the use of copper under sewage leads us to hope that it will be satisfactory for this purpose.

**Mechanisms for Operating Wooden Racks in Settling Tanks.**—In our small experimental plant the racks have been agitated or shaken by hand. In a large installation it would be necessary to do this mechanically.

Professor Rudolph Michel, of the University of Illinois, College of Engineering, was asked to report on the design of a mechanism to accomplish the necessary agitation of the racks. After several conferences with Mr.

G. C. Habermeyer, Engineer of the State Water Survey, Professor Michel has submitted the following report:

In arriving at a suitable design of a mechanism for raising and lowering a series of wooden racks immersed in the sewage, five different schemes were considered.

1. For cylindrical tanks, a scheme was considered to revolve a wooden rack, more or less cylindrical in shape about its vertical axis. The mechanism for accomplishing this would consist of a motor to drive a shaft through a worm reduction gear. The shaft would carry an eccentric to operate a ratchet, thus giving the rack an intermittent rotation. This scheme has the disadvantage (a) of being rather complicated, and (b) of agitating unequally the sewage with which the racks come in contact. The sewage in contact with the outer portions of the racks receives a greater amount of agitation than that which comes into contact with the racks near the axis of revolution.

2. A mechanism for revolving prism-shaped racks about a horizontal axis through their center of gravity was considered. It has the disadvantage mentioned under (b) in the preceding paragraph, and in addition is not very efficient in operation because of the fact that the racks must be made considerably smaller than the settling tanks, thus allowing considerable sewage to pass without coming into contact with the racks.

3. A mechanism for tilting racks of prismoidal shape about either end was devised. This has the disadvantage of leaving one end of the rack exposed, or very near the top surface of the sewage after the tilting operation has taken place. The racks would also have to be considerably smaller than the settling tank in which they operate, thus losing efficiency in operation.

4. A design for rotating prismoidal racks through a small arc about a horizontal axis in the plane of their top surface was considered. This scheme has the same disadvantages as were enumerated in the discussion of scheme No. 2.

5. The fifth type of scheme considered was to raise and lower the racks a distance of about four inches vertically. This mechanism would consist of a motor operating through a worm reduction gear revolving a shaft carrying the eccentrics. The eccentric rods would be hooked at the end and engage plates, thus raising the racks. Due to their buoyance, however, the racks must be weighted in order to sink. To obviate this scheme No. 6 was adopted.

This scheme is in general similar to 5, but a bell crank (see Figure 3) takes the place of the oscillating plate and a rod, attached to the bell crank, raises and lowers the racks. The latter are made to fill almost completely the volume within the settling tanks, thus giving maximum

efficiency. Every part of the rack receives the same displacement as every other part, and thus uniform treatment of the sewage is assured.

The following estimates of cost were prepared by Professor Michel and Mr. H. L. White, assistant engineer, of the State Water Survey Staff:

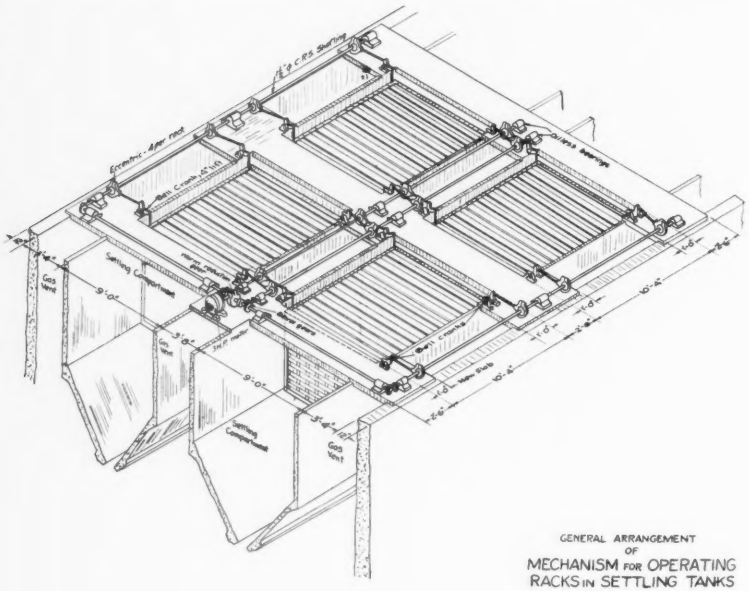



FIG. 3.

ESTIMATE OF COST OF VENERE RACKS PER 1,000,000 GALLONS

| | |
|---|---|
| Veneer strips for 480 mats size 4 feet by 8 1/2 feet ($3.00 per thousand pieces 1/16" x 1" x 72") | $ 162.00 |
| Freight for veneer | 35.00 |
| Labor weaving | 960.00 |
| Wire, 18-gage copper wire, 5 wires to the mat (20¢ per 100 feet) | 30.00 |
| Wood frame ($40.00 per thousand board feet) | 30.00 |
| Pipes for air distributor: | |
| 128 feet of 1 1/2-inch galvanized pipe at 20¢ per foot | 26.00 |
| 100 feet of 3-inch pipe at 50¢ per foot | 50.00 |
| Pipe fittings | 17.00 |
| Labor for assembling—30 days, $5.00 a day | 150.00 |
| Total | $1460.00 |

ESTIMATE OF COST OF BLOWER

| | |
|---|---|
| Equipment to deliver 110 cubic feet of free air per minute at 4 pounds per square inch pressure: | |
| Blower | $ 200.00 |
| 5-horsepower motor | 60.00 |
| Freight, drayage and installation | 140.00 |
| Total | $ 400.00 |
| Equipment to deliver 367 cubic feet of free air per minute at 4 pounds per square inch pressure: | |
| Blower | $ 460.00 |
| 10-horsepower motor | 100.00 |
| Freight, drayage and installation | 190.00 |
| Total | $ 750.00 |

ESTIMATE OF COST FOR RACK SHAKER

| | |
|---|---|
| Motor, 3 H. P., 1200 r. p. m., 60 cycles, 220 volt, 3 phase | $ 100.00 |
| Worm gear reducer (ratio 40:1) | 85.00 |
| Shafting, 136 feet of $1^1/_2$-inch cold-rolled shaft | 40.00 |
| 16 eccentrics and eccentric straps (2" throw) | 160.00 |
| 16 eccentric rods | 10.00 |
| 4 sets of mitre gears C. I. | 80.00 |
| 16 oilless bearings for $1^1/_2$-inch shaft | 150.00 |
| 32 small cast-iron bearings for bell cranks | 50.00 |
| 16 bell cranks | 20.00 |
| Switch for starting motor | 30.00 |
| Concrete foundation mechanism | 50.00 |
| Bolts, nuts, keys, and vertical rods to mats | 25.00 |
| Labor of installing | 150.00 |
| Freight | 50.00 |
| Total | $1000 00 |

The researches here reported were carried out in part with funds furnished by the Chemical Foundation.

# Odor Control by Chlorination[1]

BY R. F. GOUDEY[2]

Considerable experimental work has been done in California, at Whittier, Davis, Porterville, Tulare, Wasco, and the Orange County cities, on the problem of control of odor nuisance by chlorination. The work at Whittier, Davis and Porterville proved promising, but was not carried beyond the preliminary stages.

At Wasco, Mr. E. A. Reinke, of our Bureau, found that creamery wastes, when chlorinated and disposed of by broad irrigation, would not become odorous if the wastes seeped away into the ground within 18 or 20 hours after chlorination. The total cost of the chlorination was only 0.020 cent per gallon of milk received at the creamery. This remarkable discovery was corroborated by similar work done on a larger scale at Tulare. Wasco was the first community to adopt chlorination of creamery wastes as a method of overcoming a gross odor nuisance. The city of Newport Beach is the first and only city in California now regularly employing chlorination for control of odors from its Imhoff tank, located alongside a highway.

There is particular need for odor control at treatment plants and in outfall sewers in California for the following reasons:

1. Population density is increasing and neighbors are generally resentful of the odors and even of the works themselves.
2. Outfall sewers are relatively long and the sewage becomes stale.
3. Most of the water supplies are low or lacking in dissolved oxygen and have high mineral sulphate content, conditions which tend to accelerate the production of hydrogen sulphide gas in sewage.
4. The sewage is relatively concentrated, high in oxygen demand, and rarely diluted with infiltration or runoff.
5. High temperatures prevail throughout the summer period.

Particularly bad odor conditions have existed along the old Los Angeles outfall sewer, the Orange County outfall, and the El Centro outfall, all of which have caused odor nuisances covering literally many square miles of territory.

Control of odors from outfall sewers, as distinguished from control of odors at treatment plants, is a rather new development. One of the first articles dealing with odor control on outfall sewers appeared in *Engineering News-Record*, **98,** 16, in connection with work done by this Bureau on the El Centro outfall sewer. Resort was had to such expedients as using copper sulphate, running the sewers full, closing vents, and other

[1] *Presented at First Annual Meeting of the California Sewage Works Association, San Bernardino, Calif., Oct. 26, 1928.*

[2] *Resident Engineer, Los Angeles, California State Department of Public Health.*

suggested methods for control of odors, but all methods were either too costly or were impractical.

Two years ago Mr. L. H. Enslow, of the Chlorine Institute, learned of the work being attempted at El Centro and offered to assist in experimenting with chlorine gas as an odor retardant in sewage. Owing to the remoteness of our office from El Centro, it was decided to try out the scheme on the Orange County outfall sewer system. There was imperative need of work being done on the Orange County outfall, inasmuch as hundreds of complaints of odors had been received.

The Bureau, in coöperation with Mr. Enslow, and with the Wallace and Tiernan Company, which provided chlorinators and assisted in collection of samples, and with further assistance from the Orange County Health Department in analyzing samples and assisting in the collection of other samples, carried on this experimental and demonstration work on several occasions over a period of two years. At times there were as many as four men in the field. The total cost of the demonstration work, exclusive of Bureau time and expense, was over $5000, the object being primarily not only to experiment but to demonstrate on a large and practical scale the influence of chlorine. The last series of tests included over 500 determinations. Thus no small amount of data has led to the conclusions reached, which are nevertheless regarded as tentative.

## Description of Orange County Outfall Sewer System

The Orange County cities, consisting of Fullerton, Anaheim, Orange and Santa Ana, with a total population of about 70,000, are linked together by an outfall sewer system 26 miles long, varying from 18 to 42 in. in diameter. All gravity sewers are laid on satisfactory grades, giving minimum velocities of three feet or more per second. Diagram No. 1 gives a general plan of the outfall sewer system. At the upper end the flow is only 300,000 gal. per day, and at the lower end 5,000,000 gal. per day. The sewage rarely flows more than one-half the depth of the sewer. Seven miles below the upper end of the sewer system the sewage from La Habra and West Fullerton is pumped through an 18-in. main, two miles in length, to join the gravity sewer serving the city of Fullerton. The detention period of the sewage in this force main varies from 10 to 20 hours, averaging 12 hours.

A chlorinator, No. 1, was installed at the head of the La Habra-West Fullerton pumping plant. The second chlorinator was installed just below the Anaheim sewer, which is approximately $2^1/_2$ miles below the junction of the force main just mentioned and the Fullerton sewer. This was the only convenient place at which a chlorinator could be erected, but the sewage contained more hydrogen sulphide than was desirable. The effect

of the chlorination, however, was quite satisfactory and indicated what could be done if the chlorinator were installed farther up the line.

Although no chlorinators were used on the Orange and Santa Ana branches, chlorination of the Anaheim sewage counteracted odors from the Orange city sewage in the outfall. The sewer system is laid out in such a way that if Santa Ana and Orange sewages were chlorinated, and the Anaheim chlorinator moved up to Fullerton, judging by the effects of the two which were actually used, odors in the entire system would be amply controlled.

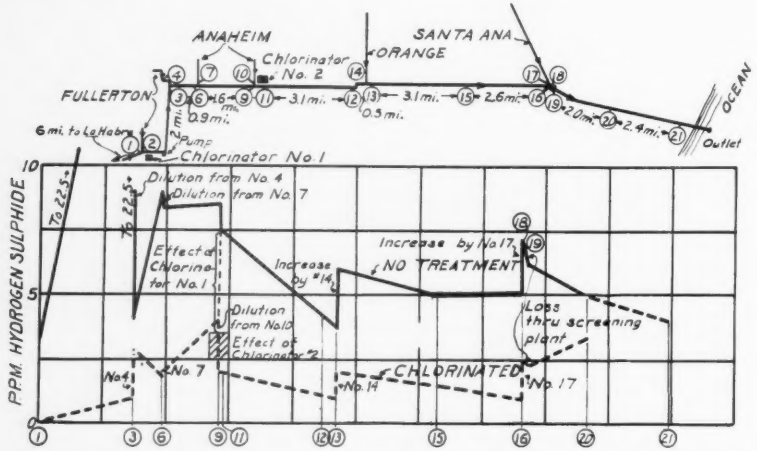



Diagram 1.—Concentration of Hydrogen Sulphide in Sewage, Outfall Sewer System, Orange County, California.

The upper chlorinator, No. 1, gave best results at a dose of 50 lb. per day, which is equivalent to 150 lb. per million gallons. At times residual chlorine was noted at the end of the two-mile force main. Chlorinator No. 2 was operated at 150 lb. a day, giving a dose of about 80 lb. per million gallons.

The time of flow of sewage from Fullerton to the ocean is nine hours, and from La Habra to the ocean 21 hours. The time of flow from chlorinator No. 2 to the screening plant, Station 16, is 5 hours.

## Phenomena of Odor Production

Attention is first called to Chart No. 2, which with one exception shows hydrogen sulphide concentrations with no chlorination. These curves show the hourly variations of hydrogen sulphide in the Fullerton sewage, and the Fullerton-Anaheim and Orange sewage, at Station 16. Both curves represent the extremes of the system, indicate similar character-

istics, and prove that the hydrogen sulphide production is related to sewage flow.

These analytical results apparently indicate that when the sewage nears the average flow mineral sulphates are attacked, producing various sulphides, including hydrogen sulphide. The sulphate-splitting organisms apparently start their breaking-down action along the sides of the sewer, in the absence of dissolved oxygen, and when the sewage is but two to three hours old. The hydrogen sulphide increases rapidly and reaches a maximum concentration soon after the sewage flow passes its peak. It then falls off rapidly as the sewage flow declines. At minimum flow dissolved oxygen is present practically the entire length of the outfall but there is no hydrogen sulphide. The hydrogen sulphide seems to form initially at a very high rate, in fact, faster than it can be released, but as the sewage flows down the outfall, the rate of release is greater than the rate of production. At the lower end the hydrogen sulphide remains fairly constant. Mineral sulphates are reduced to sulphides in the upper portions of the sewers but the sulphides are re-oxidized to almost the initial content of sulphates in the lower reaches.

The only continuous routine tests were for hydrogen sulphide and mineral sulphates. Dissolved oxygen, hydrogen-ion and temperatures were determined occasionally. Analytical methods for determination of hydrogen sulphide and mineral sulphate are somewhat inaccurate, and even though accuracy were possible these two tests are not sufficient to study the complete sulphur cycle. Various methods for hydrogen sulphide determinations were used. The most satisfactory technique was suggested by Enslow. His procedure gave consistent results for volatile sulphides and was checked in the field repeatedly by four independent technicians. Great care was taken to obtain the proper end point.

On one survey mineral sulphates were determined in the filtered sample by the turbidimeter method. On others, composite samples were collected and analyzed in the laboratory for total sulphur, after adding bromine to oxidize sulphides; another sample was acidified with hydrochloric acid, heated to drive off sulphides, and sulphates were determined in the residual solution. The difference gives the total sulphides. There is need of a good technique for field determinations of the various sulphur compounds in sewage.

Because of the uncertainty of results for hydrogen sulphide in amounts lower than 1 p. p. m., and because the hydrogen sulphide production appears to be correlated with rate of sewage flow, hourly curves were made of all stations regardless of the days the samples were collected, and average, maximum, and minimum values were taken over the highest 7-hour period. Diagram No. 1 shows averages for the 7-hour high range.

As expected, the two-mile force main, where the velocities averaged

about 0.15 ft. per sec., produced the most hydrogen sulphide, averaging 24 p. p. m. or about 2 p. p. m. per hour.

The hydrogen sulphide in the Fullerton sewage averaged 4.5 p. p. m., bringing the mixture to about 4 p. p. m. The addition of septic sewage from the force main to the relatively large volume of sewage (three times greater) in the Fullerton outfall, caused a very sharp increase in the rate of production of hydrogen sulphide, to such an extent that the rate of increase in the hydrogen sulphide production was greater than the rate of release. In the short distance of 0.9 mile the hydrogen sulphide increased from 4 to 9 p. p. m.

The first connection below the junction of the Fullerton line with the force main was at North Anaheim, 0.9 mile below. Slight dilution kept the hydrogen sulphide fairly constant for the next 1.6 miles. Anaheim sewage diluted the sewage at this point, to give an average hydrogen sulphide content of 7.5 p. p. m.. There were no connections to the sewer for the next 3.6 miles, which for 3.5 miles had no break in alignment, and but very minor changes in grade. During flow through this section there was a marked decrease in hydrogen sulphide production, the average hydrogen sulphide in the sewage being reduced from 7.5 to 3.7 p. p. m.

At this point a long outfall sewer entered from Orange. The sewage was high in hydrogen sulphide, causing an increase up to 6 p. p. m.. For the next 5.7 miles there were no new connections and the rate of hydrogen sulphide production was again approximately equal to the rate of release. The Santa Ana outfall increased the hydrogen sulphide to 7.2 p. p. m. at the screening plant (Station 18). About 1 p. p. m. was lost through the screening plant, and the hydrogen sulphide content of the effluent continued to decrease on the way to the ocean, 4.4 miles distant.

This study indicated that the hydrogen sulphide production was rather sudden in its onset but slow to diminish. Additions of fresh or stale sewage to septic sewage quickly increased the hydrogen sulphide. In sewage 9 or 10 hours old the rate of production was apparently slower than the rate of liberation.

### Influence of Chlorination

Chlorination of the sewage brought out some very remarkable findings. The No. 1 chlorinator was successful in reducing the hydrogen sulphide from an average of 24 p. p. m. down to about 1 p. p. m., and toward the end of the experiments the hydrogen sulphide at the end of the force main was invariably absent. This is a very significant finding. If an attempt had been made to neutralize the hydrogen sulphide at the end of the force main, it would have required approximately 75 p. p. m. of chlorine, equivalent to about 220 lb. of chlorine per day. By destroying the sul-

phate-splitting organisms before hydrogen sulphide was produced in large quantities and continuing to inhibit their growth, a dose of 50 lb. per day, equivalent to 17 p. p. m., was sufficient. This clearly shows the need of giving proper study to the location of chlorinators on such work.

The mixing of the relatively small volume of chlorinated sewage from the force main with Fullerton sewage had the effect of diluting the Fullerton sewage somewhat, but, what is far more important, chlorination actually brought about a decrease in hydrogen sulphide in the mixture, whereas formerly, without chlorination, there had been a very marked increase. (Note that at Station 6 the effect of chlorination on 300,000 gal. per day, mixed with 3 m. g. d. of Fullerton sewage, showed a reduction from 9 to 1.7 p. p. m.) This can only be explained by the action of end products of chlorination, such as chloramines, chloroproteins and other chloro-products. The presence of chloramines was in evidence in the manholes below No. 2 chlorinator in the form of a light, smoky gas.

Sewage from North Anaheim, entering at Station 7, contains packing house waste. Chlorine end products were no longer able to repress sulphate reduction in this strong sewage, consequently there was an increase in the rate of hydrogen sulphide production. Dilution by Anaheim sewage brought down the hydrogen sulphide to 3.5 p. p. m., whereas before chlorination 7.5 p. p. m. were present. This reduction can again be explained only by the action of end products, rather than actual reaction of hydrogen sulphide and chlorine. Such a reaction would have required the use of 160 lb. of chlorine whereas only 50 lb. did the work when applied at the upper end.

The second chlorinator reduced the hydrogen sulphide from 3.5 to 2 p. p. m., giving a reduction of 1.5 p. p. m. Theoretically, there should have been a reduction of 4 p. p. m. The reason for this difference needs further study. One of the factors was the high chlorine demand of packing-house wastes present in the sewage from North Anaheim (Station 7). Notwithstanding the presence of this strong sewage the chlorination caused a continuing decrease in the hydrogen sulphide in the sewage for 9.3 miles, in spite of a heavy increase in hydrogen sulphide content from the Orange sewer, which entered 3.6 miles below. The second chlorination reduced the hydrogen sulphide to less than 1 p. p. m. above the Orange connection; below this connection the hydrogen sulphide was held down to 2 p. p. m., apparently due to the end products of chlorination. The hydrogen sulphide content thereafter markedly decreased to less than 1 p. p. m. at the screening plant. The effect of both chlorinators was to reduce the hydrogen sulphide from 5 p. p. m. to less than 1 p. p. m. for the combined sewage of Fullerton, Anaheim, Orange and La Habra at Station 16. The chloro-compounds in this combined sewage materially reduced the hydrogen sulphide in the mixture over what theoretically should have obtained from

the addition of the Santa Ana sewage. Less hydrogen sulphide was removed by the screening plant than before chlorination, but below the screening plant there was a marked increase in hydrogen sulphide production where, without chlorination, there had been a decrease. When the hydrogen sulphide content was kept down to 1 p. p. m. or less, odors were noticeably controlled at the pumping plant, the screening plant and along the outfall. Odors were so bad at the pumping plant before chlorination that forced ventilators had to be operated for several hours before operators could safely enter the pump pit. With the chlorinator in operation there was no odor whatever.

At the screening plant odors were particularly bad, but with chlorination there were no odors at the plant to cause nuisance. Likewise, all along the outfall, residents opposite manholes each evening would plug up the holes in the manhole covers with corks or papers and even throw several inches of dirt over the top to prevent the escape of odors. This was done every day when the manhole covers had been elevated for collection of samples before the chlorinators were in operation. One manhole below the junction of the Orange outfall, which was particularly objectionable to residents of Garden Grove, was deliberately left open when chlorination was being practiced, and there were no complaints of odors. Reliable observations were kept by an operator of a gas station near this manhole, and his comments as to when there were no odors always coincided with the times when chlorine was being applied.

## Mineral Sulphates

A number of determinations of mineral sulphates were made by the turbidimeter method, and ten samples were collected for chemical determinations. A study of the significance of the sulphate results has not yet been completed; hence supporting data for the following statements are not as yet available. The mineral sulphates of the water supplies vary materially, from 80 to 100 p. p. m. Reduction of mineral sulphates is greatest at the upper end of the sewer, continues to the point where oxidation commences, and at the lower end there is an increase in mineral sulphates. These results have been carefully studied and indicate that there is a loss of hydrogen sulphide much greater than can be accounted for by the hydrogen sulphide tests alone. This is to be expected and constitutes a check on the entire work. It is interesting to note, further, that chlorination practically stops the sulphate-splitting action and, in addition to controlling odors, prevents formation of sulphuric acid with its consequent destructive action on construction materials containing lime. By chlorinating at a cost of $3000 a year, the outfall sewer investment of nearly $1,000,000 can be saved.

## Conclusions

Results of this investigation indicate that chlorination for odor control, and less for acid formation, need not be continuous. From Chart No. 2

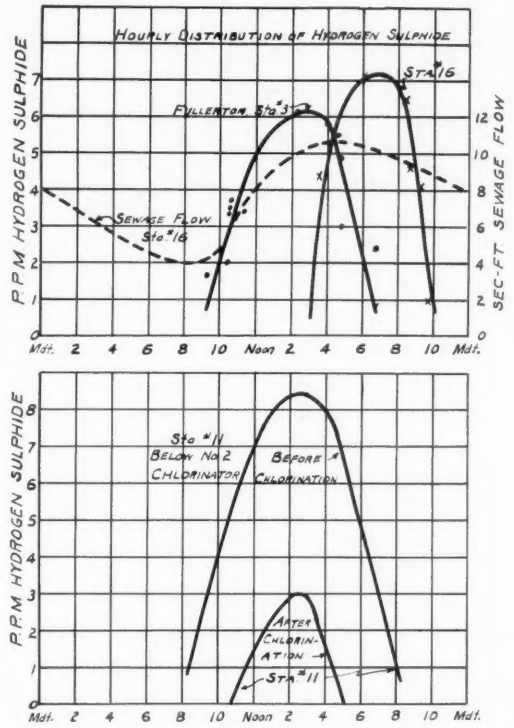

HOURLY DISTRIBUTION OF HYDROGEN SULPHIDE
P.P.M HYDROGEN SULPHIDE
SEC-FT SEWAGE FLOW
STA. 16
FULLERTON Sta. 3
SEWAGE FLOW Sta. 16
Mdt. 2 4 6 8 10 Noon 2 4 6 8 10 Mdt.
Sta. 11 BELOW No. 2 CHLORINATOR
BEFORE CHLORINATION
AFTER CHLORINATION
STA. 11

Diagram 2.—Hourly Variations in Content of Hydrogen Sulphide.

it is evident that chlorination for about a 9-hour period daily is sufficient when the sewage flow is at its maximum rate. The tests further indicate that it takes about three days after chlorination ceases before sulphide production is re-established. Accordingly, if chlorination is practised six days out of seven, good results should be obtained. Likewise, there may be no need of chlorinating on cold days or when the sewer is surcharged with rainfall runoff.

If the Fullerton sewage were chlorinated even as inadequately as at chlorinator No. 2, it is reasonable to suppose that from Stations 1 to 13 the hydrogen sulphide could be kept under practical limits of concentrations that produce odor nuisance and sewer disintegration. Although the

chlorinators were not installed at the most satisfactory points during the experiment, the hydrogen sulphide content was kept below 1.5 p. p. m. during the evening hours when odors are most noticeable. It seems remarkable that the two chlorinators as installed, with no treatment whatever of Orange sewage, gave a reduction of hydrogen sulphide at Station 16 from 5 down to 0.75 p. p. m., especially since this point is 9.3 miles below No. 2 chlorinator and 14.5 miles below No. 1 chlorinator.

The entire line could probably be most effectively controlled by one chlorinator at the pumping plant, operating continuously, and separate chlorinators at Fullerton, Orange and Santa Ana city limits. The total chlorine consumption would then be 150 lb. per day.

Chlorination of sewage at a point where the hydrogen sulphide was 3 p. p. m., or less, effectively prevented hydrogen sulphide production from splitting of mineral sulphates, and not only retarded such action for 20 hours, if not mixed with other sewage, but even when mixed with three times its volume still further retarded hydrogen sulphide production for 7 hours, probably through the action of chloro-products.

## Discussion

In reply to a question by Mr. Schuyler, Mr. Goudey gave the cost for chlorine on the Orange County outfall tests as $1.75 per million gallons, and stated that where sewage is to be treated the effect of pre-chlorination can only be inferred from the results at hand, which indicate a decrease in oxygen demand. He added that it would also reduce the area of pollution around ocean outfalls. At Bath, England, pre-chlorination has controlled odors at a plant 20 miles below the point of application. Mr. Kennedy remarked that at Schenectady experiments indicated that pre-chlorination did not materially affect oxidation of sprinkling filters.

Mr. Rawn asked if any particular data had been obtained on controlling deterioration of concrete by means of chlorine and asked if soluble chlorides would not injure the sewer. Mr. Goudey replied that if free chlorine had any bad effect it would only be over a distance of 400 to 500 ft. as it would all be used up in that distance. He attributed disintegration in part to splitting of mineral sulphates by bacterial action and concluded that if chlorination prevents this breaking-down of mineral sulphates there can be no disintegration from that action, as the "mineral sulphate cycle" is stopped at its source. In his experience disintegration occurs where sulphides are above 3 p. p. m. and it may be that by keeping below that value it can be stopped. However, by chlorination hydrogen sulphide can be kept below 0.5 p. p. m.

In reply to a question by Mr. Reinke, Mr. Goudey gave the experience along the Orange County outfall sewer when industrial wastes with 1600

p. p. m. sulphates were discharged into it. Hydrogen sulphide was at least two or three times as great as it was previously and disintegration took place rapidly for a year and a half due almost entirely to the industrial wastes, which were finally eliminated from the sewer. Mr. Warren inquired what the effect would have been on these experiments if the discharge of the industrial wastes had continued into the sewer. Mr. Goudey replied that it was hard to tell and far safer to keep them out. Mr. Warren agreed with this policy but felt that industrial growth should be encouraged. Mr. Goudey answered that in this case although the company spent $125,000 for equipment to produce acetic acid, potassium sulphate and ammonium chloride from the wastes, they made money on these by-products.

Mr. Chester Smith stated that with industrial wastes it was simply a case of experimenting to find out what dose of chlorine was necessary to repress sulphate-splitting organisms. Mr. Warren brought out the necessity of determining the chlorine demand, emphasizing that in some cases, as at Hyperion, the cost might be prohibitive. Mr. Goudey suggested that control should be near the head of the sewer line rather than at the lower end of the outfall.

# Mechanical Aerator at Des Plaines River Treatment Works

BY M. B. TARK[1]

During the past few years activated sludge plants using diffused air have increased rapidly in the United States and Canada, but mechanical aerators are comparatively rare. This is in direct contrast to the situation in England, where the volume of sewage treated by mechanical means is twice that treated by air. A new aerator that promises improvements over the older types will therefore be of interest.

## Design of Tanks

In January, 1927, the Link-Belt Company began experimenting with such a machine at their Philadelphia shops. A tank 10 ft. long, 15 ft. wide and 10 ft. deep was constructed and a number of aerators were tried out until a machine was developed that gave good agitation and imparted a fairly high velocity to the sewage at a reasonable expenditure of power. The aerator is a ribbon conveyor, pitched both ways to give approximately the same spiral circulation as is obtained in the Manchester or spiral-flow tank.

Every aeration tank must be designed to prevent settling of solids in any part of the tank during operation, and to stir up and carry back into circulation all material that will settle out during a temporary shut-down of the plant. A velocity of 1.0 ft. per sec. at the bottom of the tank will apparently do this, but to be on the safe side, experiments were continued until a velocity of 1.5 ft. per sec. was obtained. The surface velocity is about double that of the bottom velocity.

Following the plant experiments a mechanical aerator 26 in. in diameter was designed. This was mounted in a narrow trough carried on a baffle, which ran the whole length of the tank. The speed varied from 36 to 60 r. p. m., depending on the strength of the sewage, period of detention, and width of the tank. A tank 10 ft. deep and 20 ft. wide was found to be the most economical size. Indications were that the length of each aerator might be limited to 250 ft. although several units can be placed in one tank if a longer tank is found desirable.

## Experimental

Only clear water and sand were used in the experimental tank at Philadelphia, as sewage could not be obtained. After the preliminary work was completed, the Sanitary District of Chicago continued the experiments at the Des Plaines Sewage Treatment Works at Maywood, Illinois. An existing tank—11 ft. 2 in. wide, 10 ft. deep and 21 ft. long, with a volume

[1] *Engineer, The Link Belt Company, Philadelphia.*

of 16,500 gallons—was equipped with the mechanical aerator. The settling tank was 14 ft. 2 in. in diameter, with a volume of 7720 gallons. The submerged orifice boxes for regulating the flow of the sewage and sludge were not changed. The air-lift for the sludge return was placed inside the settling tank to keep it from freezing. The scrapers of the rotary collector in the settling tank had to be cut to clear the air-lift pipe, which

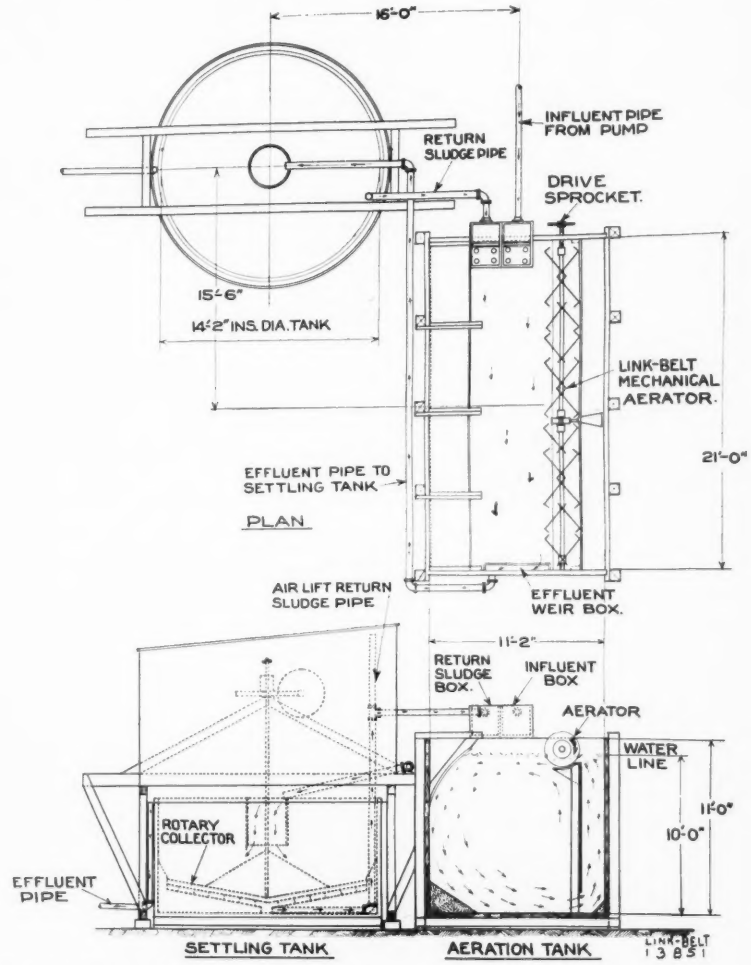



FIG. 1.—Link-Belt Mechanical Aerator for Chicago Sanitary District, Des Plaines Sewage Treatment Plant at Maywood, Illinois.

left a space about 8 in. wide around the circumference of the tank, from which the sludge was not removed by the scrapers. Later it was found that the sludge in this part of the tank turned septic and may have had a detrimental effect on the operation of the plant. Before reaching the aeration tank the sewage passed through a grit chamber and a fine screen with $^1/_{16}$-in. slots.

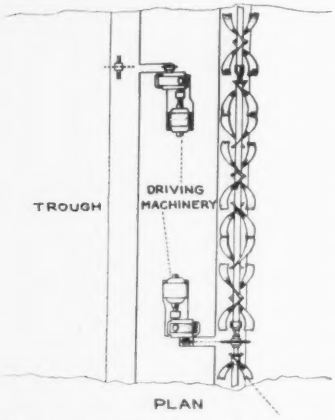



FIG. 2.—Link-Belt Mechanical Aerator Design of Ribbon Conveyor.

At the start the aeration and settling tanks were filled to one-quarter of their capacity with activated sludge from the diffused-air plant and then raw sewage was added to capacity. The aerator was started on January 13, 1928. Mechanical troubles soon developed; the longitudinal partition swelled up and pushed the trough against the aerator. The machine had to be stopped several times and the trough lowered. On January 19 a heavy wind deflected by the superstructure over the settling tank stirred up the contents. A tarpaulin placed over the tank on the weather side corrected this disturbance. This tarpaulin was used thereafter whenever a heavy wind occurred.

One pump of limited capacity furnished the sewage for two experimental units and the period of detention was determined by the capacity of the pump.

The speed of the aerator at the start was 48 r. p. m. The nitrates decreased rapidly from 8.70 to .90 p. p. m. The decrease may have been due to the increase of total nitrogen in the influent but more probably was caused by the change from diffused to contact air. After the first drop the nitrates built up again and the plant gave a fair effluent until February, 1928, when the main pump was shut down to make some changes in the suction well. After starting operation, a valve in the main aeration tanks was left open, causing a short circuit, and accounting for the high suspended solids in the influent and for the poor effluent.

During the early part of March, 1928, the sludge in the settling tank had accumulated until it reached within a few inches of the surface of the tank. Provision for wasting the sludge was then made. From March 10–20 a total of 6050 gallons of sludge was withdrawn. The moisture content averaged 97.78 per cent. After the withdrawal of the sludge, normal operating conditions prevailed until April 3, when the plant was shut down

Link-Belt Mechanical Aerator Operating Data

Results in Parts per Million

| | Influent | | | | | | | | Effluent | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Nitrogen | | | | | Nitrogen | | | | |
| Month 1928 | Flow 1000 G. P. D. | Detention Period | % Sludge in Tank | 5-day B. O. D. | Suspended Solids | Total | Organic | Free Ammonia | 5-day B. O. D. | Suspended Solids | Total | Organic | Free Ammonia | Nitrites | Nitrates | Total |
| Jan. | 46 | 6.67 | 14.5 | 146 | 140 | 16.6 | 5.0 | 11.6 | 17.8 | 30.5 | 5.25 | 2.09 | 3.16 | 0.62 | 6.28 | 6.90 |
| Feb. | 43.5 | 6.98 | 24.5 | 162 | 191 | 17.7 | 5.6 | 12.1 | 18.5 | 24.9 | 3.46 | 0.73 | 2.73 | 1.21 | 4.43 | 5.64 |
| March | 43.4 | 7.01 | 30.7 | 166 | 179 | 17.9 | 6.6 | 11.3 | 16.6 | 17.3 | 5.53 | 1.59 | 3.94 | 0.47 | 3.58 | 4.05 |
| July | 52.4 | 6 | 20 | 91.7 | 149 | 8.68 | 3.06 | 5.62 | 9.6 | 24 | 3.34 | 1.46 | 1.88 | 0.83 | 2.98 | 3.81 |
| Aug. | 52.4 | 6 | 20 | 122 | 109 | 11.0 | 5.5 | 5.5 | 8.4 | 24 | 3.32 | 2.42 | 0.90 | 0.68 | 1.44 | 2.12 |
| Sept. | 52.4 | 6 | 20 | 162 | 94 | 13.8 | 4.20 | 9.68 | 15.9 | 23 | 4.40 | 2.45 | 1.95 | 1.30 | 3.68 | 4.98 |

B. O. D. analysis made daily. All others once every two days.

until a larger pump for supplying the experimental units with raw sewage was installed.

The aeration and settling tanks were emptied and the septic condition in the settling tank was then discovered. Whether the septic sludge affected the biochemical oxygen demand of the effluent is a matter of opinion. Concrete has been filled into the space between the walls of the tank and the scrapers and sloped towards the scrapers so that the accumulation of sludge will be greatly reduced in the future.

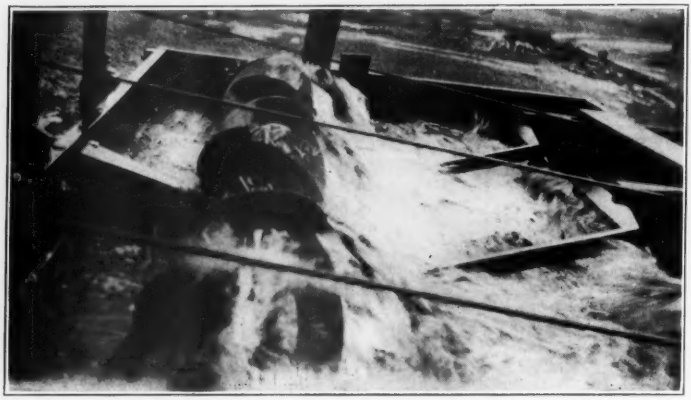


FIG. 3.—Link-Belt Mechanical Aerator in Operation.

## Summary

The results obtained by six months of operation (Table I) indicate that a stable effluent is obtained with a period of detention of 6 hours, if the influent is average domestic sewage with an average biochemical oxygen demand of 150 p. p. m. The moisture content of the sludge is low. Whether this is due to the method of aeration or to the comparatively shallow aeration tank is not known.

The power consumption for the 10-ft. tank at Philadelphia and the 21 ft. tank at the Des Plaines Works was about the same. At a speed of 42 r. p. m. the motor output was .65 h.p. at Philadelphia and 1.35 h.p. at Maywood. On this basis the theoretical power for a tank of 1 m. g. d. capacity, 210 ft. long will be 13.5 h.p. Adding to this the mechanical and electrical losses, the total power required will be about 20 h.p.

After the installation of a new pump and repairs to the settling tank, the aerator was again put into operation in the middle of July, 1928, and as a larger volume of sewage is now available, it will be possible to operate with shorter periods of detention.

# Sewage Works Operation

## The Operation of Imhoff Tanks[1]

By H. M. Beaumont[2]

### Principles of Successful Operation

The satisfactory operation of Imhoff tanks requires intelligent and conscientious supervision founded on a thorough understanding of the purposes of the tank and the fundamental principles involved. Well-designed tanks improperly operated have failed to produce satisfactory results, while others of less favorable design have, by skilful manipulation, been made to give results which have been regarded as excellent. Even in the case of well-designed and properly operated tanks, difficulties are likely to arise at times which will tax the ingenuity of the most skilful operator.

Reports of analyses and tests should be recorded and receive the careful study of the operator. In addition thereto, the importance of keeping a diary of the work done and of observations made cannot be overestimated. The operator should take advantage of any laboratory assistance at hand. He should insist that the structures and grounds present a well-kept appearance and that cleanliness and neatness be maintained at all times. He should strive to create the interest of the public in the sewage works by having them visit it. A bushel of air-dried sludge donated to a tax payer for use in his home garden will at times awaken an interest which may be passed along to others.

Where trade wastes are of sufficient volume or of a character to affect adversely the life of the structures or the operation of the tanks, the operator should acquaint himself with the origin of these wastes and take appropriate action to eliminate or neutralize their harmful constituents.

### Functions of the Imhoff Tank

The purpose of the Imhoff tank is to remove by sedimentation the settleable suspended particles present in the sewage, and by bacterial digestion to liquefy, gasify and stabilize the organic matter present in the resulting sludge, all of which is to be accomplished in the same tank and without contaminating the settling sewage with the products of sludge digestion.

[1] *Presented at Third Annual Conference, Pennsylvania Sewage Works Association, Pennsylvania State College, July 10, 1928.*

[2] *Asst. Engineer, Bureau of Engineering and Surveys, Philadelphia, Pa.*

To accomplish these purposes, the Imhoff tank is a two-story structure, the upper compartment serving for sedimentation and the lower for biochemical digestion. A trapped slot between these compartments provides a means for the solids intercepted in the upper chamber to pass into the lower chamber, reserved for sludge digestion. The gases resulting from decomposition, together with gas-laden particles of sludge, are not permitted to enter the settling compartment, but are deflected by the trapped arrangement of the slot and rise in the scum chamber where the gases escape into the atmosphere through the gas vents. In a properly working tank, these gases should be rich in methane and have a slightly tarry odor.

The character of sewage obtaining at different sewage works varies considerably, and at the same plant there may be seasonal, daily and even hourly variations. Uniformity is generally lacking in Imhoff tank operation. Varying results in the operation of the several tanks are observed in a given plant and where multiple digestion compartments are provided in a single tank, different reactions may be found in each of the compartments.

Corrective measures employed in a given sludge compartment with satisfactory results have failed when applied to another when treating the same sewage and supposedly under identical conditions. Therefore, in this paper no attempt is made to suggest a formula which will insure the satisfactory operation of Imhoff tanks at all times and under all conditions, but rather to point out some of the difficulties encountered in the field, the means employed to meet these difficulties and the results obtained from the application of the measures adopted.

## Start of Operation of Imhoff Tanks

As sludge digestion is greatly retarded during times of low sludge temperature, very little digestion takes place during the first four months of the year in those latitudes where relatively long, cold winters prevail. In such locations it appears that the starting of tank operation should be preferably in late spring or the summer season.

The practice of filling the tanks with water or very weak sewage immediately before starting operation appears to be helpful. It is believed this method favors satisfactory sludge digestion and perhaps lessens the danger of foaming.

Seeding the tanks with well-digested sludge and various kinds of manure have been tried at different places with more or less success. The failures reported have generally been attributed to insufficiency of seeding material. It is also true that unseeded tanks have in many instances given results comparable to those obtaining where supposedly ample seeding material was used.

## Character of Sewage

Sewage from combined sewer systems contains at times considerable quantities of sand from street washings. Grit chambers are usually provided to remove this material from the sewage prior to its passage into the Imhoff tank.

Depending upon the efficient operation of the grit chamber, more or less sand will escape into the tank and be deposited in the sludge digestion compartment. If considerable quantities of sand are deposited the biochemical activities may be checked and the resulting sludge poorly digested and difficult to remove from the tank. It is held by some that the presence of small amounts of sand in the sludge tends to weight down the lighter organic particles and thus prevent excessive scum formation.

Where the sewage contains appreciable quantities of rags, paper and sticks, coarse screens should be provided to intercept these materials, as they have a tendency to choke the slot between the settling and sludge digestion compartments, do not readily respond to bacterial digestion, may be the cause of poorly digested sludge, and add difficulty to withdrawal of sludge from the tank. Frequent cleaning of the screen is desirable to prevent retarded velocities in the sewer.

## Efficiency of Settling Compartment

The efficiency of the settling compartment is determined by the per cent removal of the settleable suspended solids. With a 2- to 3-hour detention period, it is quite common to effect a removal of 100% of the settleable solids as measured in the Imhoff cone glasses and 60% or more of the total suspended solids as determined by the Gooch crucible.

A long settling period tends to produce a septic effluent, which is detrimental to the operation of oxidizing beds, should such treatment be required.

It is also of great importance that the solids resulting from sedimentation be distributed as uniformly as is practical among the several tanks and also among the individual sludge digestion compartments. Where provision has been made for flow reversal through the tanks, the direction of flow should be changed at weekly intervals if possible.

The arrangement and location of baffles have at times an appreciable effect upon the tank efficiency and often a slight rearrangement of the baffles will result in greater removals of settling solids and their more uniform distribution in the sludge digestion compartment.

Floating materials such as oil, grease, fruit parings, match sticks, etc., detract from the general appearance of the tank, attract flies in warm weather, and may give off objectionable odors. As this material does not readily respond to bacterial digestion, it should be burned or buried after skimming from the tanks.

The frequent use of a squeegee insures the removal of solid material which may impinge along the sloping walls of the settling compartment. Influent, effluent and reverse-flow channels should be kept free from sewage deposits and growths at all times. To insure the efficiency of the slot, frequent cleanings and the determination of the surface level of the digesting sludge are necessary.

### Processes in Digestion Compartment

In the matter of sludge digestion, the processes involved appear to be very complex, and while considerable research has been done the field for further study is great. Experience indicates that with a favorable environment it is possible to convert the unstable organic matter resulting from sedimentation into liquids, gases and more stable material, so that when the sludge is withdrawn from the tank, it will be free from offensive odors, flow freely, and will dewater itself rapidly in favorable weather when distributed over sand drying beds.

There is considerable evidence to indicate that several stages are involved in the processes of digestion. For practical purposes, a reference to the grouping suggested by Rudolfs will suffice:

(1) A period of intensive acid production during the decomposition of the soluble carbon compounds, and the breaking down of cellulose. Organic acids are formed at a greater rate than they are broken down, resulting in a low pH. Large amounts of carbon dioxide are produced.

(2) A period of acid regression and acid digestion when the organic acids are decomposed at a greater rate than formed, and the accumulated material decreases. The pH approximates neutrality during this period.

(3) A period of intensive digestion of more resistant materials during which time biological balance is being established. A greater production of methane and a pH above neutrality characterize this stage.

If the processes of digestion do not proceed beyond the first stage, it is suggested that foaming may result or the sludge may be poorly digested.

### Operating Experiences at Northeast Works, Philadelphia

In line with these suggestions, the following memoranda concerning operating experiences at Philadelphia are offered for whatever value they may have:

At the Northeast Sewage Works, Philadelphia, the sewage treated is probably 3 to 6 hours old when it arrives at the works. It has a suspended solid content of about 200 p. p. m. and contains much trade waste and appreciable quantities of oil and grease. Ether-extracted fat is reported as about 90 p. p. m.

The Imhoff tanks, of the reverse-flow type, were placed in operation late in 1923. In the summer of 1924, moderate foaming occurred, but

only light foaming was noted in the gas vents during the summers of 1925 and 1926. During these times of foaming, the pH of the supernatant liquor above the digesting sludge was varying between 7.2 and 7.4. Moderate foaming occurred in the early summer of 1927 and during the foaming the pH was reported as 6.8. The foaming period extended over 4 weeks. During the period, May 15 to July 1, 1928, a more persistent foaming occurred, with a pH of 6.6 to 6.8 obtaining during the foaming period.

At these works, with 32 Imhoff tanks of 6 sludge hoppers each, the matter of adding lime to the sludge would involve a considerable expenditure of labor and material. Acid sludge has never been reported; the alkalinity of the sludge filtrate as determined by using erythrosine as the indicator exceeds 1000 p. p. m.

### Addition of Lime

In lieu of liming all the hoppers, lime was added to those hoppers where foaming was indicated or the pH of the supernatant was reported as less than 7.0.

During the foaming period of 1927, hydrated lime in an amount equal to 50 lb. per million gallons of sewage treated was deposited in the gas vents and beaten down with a water spray. A few days of lime application indicated improvement in the pH and a reduction in foaming.

The resting of a foaming tank also indicated an equal improvement in about the same period of time. When foaming ceased there followed a period of inactivity as was evidenced by the very slight gas ebullition in the gas vents. This in turn was followed by a thick heavy scum formation which after several days of intensive paddling resulted in a more liquid scum and normal ebullition of gas.

During March and April, 1928, every sudden rise in air temperature was accompanied by excessive ebullition of gas. This was regarded as a warning that foaming would appear with the advent of warm weather. Where pH readings of the supernatant were reported below 7.0, hydrated lime in an amount equal to 100 lb. per million gallons of sewage treated was deposited daily in the gas vents until the pH value was reported as 7.0 or higher. The volume of sludge in the tanks was greatly reduced by withdrawal.

Early in May there was a sudden drop in pH values of the supernatant, and foaming immediately started. An entire battery of tanks was given over to experimental work. Two tanks were taken out of service and rested. After 3 weeks' resting, a decrease in foaming was noted. When foaming subsided, the scum over the gas vents became dry and difficult to break up. The liquor in the settling compartment after one week's rest became rather septic and gave off unpleasant odors.

### Use of Air and Water for Prevention of Foaming

In another tank, daily applications of compressed air at 10 lb. pressure were admitted to the digesting sludge through rinsing water pipes installed at the bottom of the hoppers. Air applications of 1- to 6-minute periods were used in different sludge hoppers of the same tanks. Six-minute applications appeared to supply too great a quantity of air; two-minute applications appeared to be more practical. Foaming very quickly subsided, but the scum over the gas vents became thick and heavy, and difficult to break up. During the application of the air, oil and grease present in the sludge compartment was lifted through the slots into the settling compartment.

In another tank, 5-, 10- and 15-minute periods of application of rinsing water were added daily to the digesting sludge. The greater application proved most effective, and foaming subsided. However, the scum over the gas vent areas became lumpy, but easily broken up by paddling. Untreated river water was used, having a temperature of about 70° F., and a pH value ranging from 6.6 to 7.1.

Hydrated lime to the amount of 100 lb. per hopper, equal to about 500 lb. per million gallons of sewage treated, was applied daily to the gas vents and beaten down with water. After 10 daily applications, foaming disappeared and the pH of the supernatant increased from 6.7 to about 7.6 where it still holds 3 weeks later without adding more lime. The scum in the gas vent area is quite liquid and the gases escape without difficulty.

Using one-half of this quantity of lime in one hopper and one-fourth of the amount in another, the effect on foaming was negligible. Only a slight improvement in the pH of the supernatant after 30 daily applications of lime in the lesser amounts was noted.

### Circulation, Spraying and Paddling

In another tank well-digested sludge was raised by an air lift and deposited into the scum and foam present in the three gas vent areas. The daily amount of sludge lifted and deposited equaled 3.4 cu. yd., 6.9 cu. yd. and 10.3 cu. yd. per hopper, respectively. At the end of 3 weeks, foaming subsided and the resulting scum in the gas vent areas was quite liquid and permitted the free escape of the gases. However, only a slight improvement in the pH of the supernatant was reported. The temperature of the sludge on July 1st was 60° F.; on March 25th of this year it was reported as 50° F.

Spraying foam with water from a $1^1/_4$-in. hose and $^3/_4$-in. nozzle with a water pressure of 50 lb. was effective in knocking the foam down. One 5-minute application every 4 hours kept the most persistent foam within the gas chambers. The resulting scum was lumpy but easily broken up.

Paddling the foam with long handled hoes was also effective in knocking down foam. Paddling for 5-minute periods at 8-hour intervals was sufficient to keep the most persistent foam within the gas chamber. The resulting scum was quite liquid and permitted the free escape of the gases.

In other tanks, where normal operation obtained, the foam was beaten down and kept within the gas vents by water spray and paddling where lumpy. Foaming persisted for nearly 6 weeks. Where corrective measures were tried the foaming period was reduced to about 3 weeks or less.

## Conclusions

From observations at these works, it appears that foaming may persist for several weeks, but that this time may be reduced by corrective measures. Immediately after foaming subsides, there is a rest period, probably one week in duration, when the ebullition of gas is slight and the scum is thick and heavy and not easily broken up. Activities are again resumed, as is evidenced by normal gasification in the gas vents and the return of a heavier scum.

In spite of foaming, the sludge withdrawn has at all times been of good quality and alkaline.

At the Pennypack Works, where acid sludge resulted from the high fat content of the sewage, the phenomenon of foaming has not appeared during 15 years of operation.

# Hydrogen-Ion Control in the Digestion of Sewage Sludge on a Practical Plant Scale[1]

BY FRANK BACHMANN[2]

Numerous laboratory investigations have been made to determine the effect of lime in adjusting the pH value of sewage sludge in the process of digestion. Comparatively little, however, has appeared in the literature regarding the practical application of the principles established by these researches, even though it is generally realized that there are definite limitations to the use of lime for pH control on a large scale.

In order to collect actual plant data, questionnaires were sent to a number of engineers and operators who had supervision over plants where pH control has been or is now being tried. Thirty questionnaires were returned with all or a portion of the questions answered. Of these thirty plants, ten are of the Imhoff and twenty of the separate-digestion type. All parts of the United States are represented, although most of the plants are located in the east or middle west.

The location of the plants and name of the person from whom the information was obtained are listed below.

*Separate Sludge Digestion Tanks:* Lakeland, Fla., I. S. Tillotson; Vero Beach, Fla., H. W. Dameron; Haines City, Fla., J. P. Ferrill; Charlotte, N. C., E. G. McConnell; Monroe, N. C., E. H. Moss; Baltimore, Md., M. J. Ruark; Plainfield, N. J., John R. Downes; Merchantville, N. J., M. J. Blew; Ridgewood, N. J., A. J. Fischer; Sharon, Pa., L. E. Burnside; Fostoria, Ohio, J. F. Laboon; Milwaukee, Wis. (screenings), W. Rudolfs; Antigo, Wis., A. J. Fischer; Kiel, Wis., A. J. Fischer; Storm Lake, Iowa, C. H. Currie; Rochester, Minn., H. A. Whittaker; Sioux Falls, S. D., R. E. Bragstad; Roseville, Dunsmuir and Gilroy, Calif., C. C. Kennedy.

*Imhoff Tanks:* Schenectady, N. Y., Morris W. Cohn; Maryland, Abel Wolman; Newcastle, Pa., W. Donaldson; Trenton, N. J., F. N. Daniels; Canton, Ohio, C. C. Hommon; Decatur, Ill., W. D. Hatfield; Urbana, Ill., G. H. Radebaugh; Boone, Iowa, C. H. Currie; Virginia, Minn., H. A. Whittaker; Yreka, Calif., C. C. Kennedy.

The list of questions propounded is given in the tabulation attached hereto with a summary of the answers received. Personal opinions have been disregarded unless supported by actual operating data. An analysis of the questions and answers shows that the main points on which discussion was asked are five in number, each of which may be analyzed conveniently under separate headings as follows:

## The Beneficial or Detrimental Effect of Lime

In practically all cases the addition of lime was beneficial to digestion. In two instances the addition of lime apparently had no effect one way or the other. In certain cases, where an excessive amount of lime was

[1] *Read at meeting of American Public Health Assn., Chicago, Ill., October 19, 1928.*

[2] *Sanitary Engineer, The Dorr Company.*

used, detrimental effects were noted, taking the form of retardation of digestion, and, in one case, even causing foaming.

### Adjustment of pH Value

In general, engineers and operators attempted to adjust the reaction to the pH values recommended by research workers. Thumm and Reichle, the first to suggest pH adjustment, found good results at pH 7.8; Rudolfs and his co-workers reported values from 7.3 to 7.8 as being optimum; while the work of Fair and Carlson indicates that the optimum reaction varies during the course of digestion from an initial value of 6.8 at the start to about 7.2 at the end.

A number of the replies show that difficulties were encountered in securing pH adjustment within narrow limits, such, for example, as between 7.3 and 7.6. At large plants this would entail the use of enormous amounts of lime, while at smaller installations, where operators are not in attendance, it would be considered impracticable because of the time and careful control found necessary.

### The Form and Method of Adding Lime

Addition of lime to the incoming raw sludge was found to give best results. In general, milk of lime gave a better distribution than dry hydrated lime when added at the surface. Both gave equally good results when added to the incoming raw sludge. Where very large amounts of lime are required, it might be impracticable to add it in the form of milk of lime because of the large volume of water needed.

Good mixing of the lime with the sludge is essential, otherwise a layer effect may be obtained, *i. e.*, the pH value at different sludge depths may vary, the most alkaline condition being at the tank bottom where the lime tends to settle. Eleven plants noted this tendency, which is most likely to occur when a plant is being put in operation with no ripe sludge present as seeding material.

Where lime was added to the tank at the surface, it was generally worked into the scum with a paddle or by means of a stream of water from a garden hose. Where lime was added with the raw sludge, very good mixing was obtained. This, of course, is impossible with an Imhoff tank. In the case of two plants in which lime was added to the suction side of pumps which circulated the Imhoff sludge from the hopper to the gas vents, good mixing was also obtained. At two plants good mixing was obtained by adding the lime to the raw sewage, although it appears that this method would require relatively large amounts of lime, since some would be lost with the effluent.

The difficulties occasioned by the settlement of lime to the bottom of the tank were easily overcome by circulation of sludge. Three answers

indicate that trouble from this occurrence can be lessened by the careful addition of smaller amounts of lime at more frequent intervals.

### Foaming

Fourteen plants reported foaming in tanks where the pH values were adjusted, the pH values in nearly all cases having been maintained at about 7.3 to 7.6. In most cases foaming was attributed to a lack of ripe sludge, while three answers explained this occurrence by the more rapid gasification caused by the addition of lime.

Whether or not lime eliminates foaming still remains an open question. Six replies state that it does not, and four of these go so far as to say that the addition of lime actually increases foaming due to the more rapid digestion of sludge that has been dormant under acid conditions.

More engineers and operators, however, favor the idea that foaming is reduced by pH control, four stating that its elimination or reduction is temporary while twelve find that it is permanent. Where relief was obtained it is believed that this was due not so much to the lime *per se* but to more rapid digestion, with production of ripe sludge, which in itself is known to reduce or eliminate foaming.

### Permanency of pH and Its Control

In only five cases did the pH value fail to fall off after it was adjusted and after ripe sludge was added. In a few cases the drop in pH took place very slowly. This indicates the necessity of frequent pH determinations.

All but four of the answers showed that the addition of small amounts of lime at frequent intervals was more economical and more beneficial than the addition of large amounts at less frequent intervals, provided, of course, that the pH value had been adjusted at the start. Small amounts of lime added to very acid sludge appeared to be useless.

The answers to questions on the amounts of lime necessary to raise the pH initially to the desired value and to hold it there subsequently were rather indefinite. In general, however, it seems to be the consensus of opinion that relatively large amounts of lime are necessary to raise the pH of the raw sludge to the optimum point, but relatively small amounts are needed thereafter to maintain it on the alkaline side. Where good digestion is established and there is enough ripe sludge, no further additions of lime are required. In very small plants the cost of the lime does not appear to be a big factor. In larger ones, however, it may be a considerable item.

The amount of lime required for adjustment can be readily calculated by measuring the volume of sludge and liquid in the digestion tank and determining the amount of lime necessary to adjust the reaction of small

known volumes of liquid and sludge. From these data the total amount can be computed.

Where a large amount of acid sludge has been allowed to accumulate over a long period, *i. e.*, during the winter after a plant has been started up, it would be much better to empty the tank and start it anew in warm weather before adjusting the reaction. Otherwise, an excessive amount of lime would be required and foaming would probably result because of the absence of ripe sludge and the suddenly increased gas production.

## Acknowledgment

The writer wishes to acknowledge the kind assistance of Mr. A. J. Fischer and the engineers and plant operators who filled out and returned the questionnaires from which this information is compiled.

### QUESTIONNAIRE—REACTION CONTROL OF SLUDGE

1. Have you used lime to control the pH value of sludge in an operating Imhoff or separate digestion tank?
   Answer. 30—Yes. 20—Separate Digestion. 10—Imhoff.
2. Was it beneficial?
   Answer. 26—Yes. 2—No.
3. Was it detrimental?
   Answer. 0—Yes. 30—No.
4. What pH value did you maintain?
   Answer. 12—7.3 to 7.6 range. 16—7 to 7.6 range.
5. Were any difficulties encountered in maintaining this value?
   Answer. 14—Yes. 16—No.
6. Does your experience indicate that a narrow range of pH is essential?
   Answer. 5—Yes. 19—No.
7. What range did you find to be satisfactory from a practical operation standpoint?
   Answer. 1—6.4 to 6.8 range. 9—6.8 to 8 range. 10—7.0 to 8.0 range. 5—7.2 to 7.8 range. 2—7.2 to 8.4 range.
8. In what form was the lime added?
   Answer. 19—Dry. 15—Milk of lime. 2—Quick lime.
9. How was it added?
   Answer. 5—With raw sludge. 18—On tank surface. 2—To raw sewage. 2—To circulated sludge. 6—To tank bottom.
10. Was good mixing with the sludge obtained?
    Answer. 19—Yes. 9—No.
11. Was trouble with lime settling to the tank bottom ever experienced?
    Answer. 11—Yes. 18—No.
12. How was this trouble overcome?
    Answer. 2—Adding lime more carefully (slowly). 1—Adding smaller amounts at one time. 1—Adding lime to incoming raw sludge. 3—Circulating sludge.
13. Did foaming ever occur in a tank where the pH value was adjusted?
    Answer. 14—Yes. 15—No.
14. To what do you believe this foaming was due?
    Answer. 7—Lack of ripe sludge. 1—Poor mixing of sludge. 3—Rapid

digestion. 1—Overliming. 2—Phenol waste.

15. Will pH control eliminate foaming?
Answer. 11—Yes. 6—No.

16. Will pH control reduce foaming?
Answer. 17—Yes. 4—No.

17. If lime reduces or eliminates foaming is the effect temporary or permanent?
Answer. 4—Temporary. 12—Permanent.

18. Will pH control eliminate or reduce scum formation?
Answer. 5—Eliminates. 7—Reduces. 11—No effect.

19. Did the pH value tend to drop after it was raised to the alkaline side and ripe sludge was present?
Answer. 21—Yes. 5—No.

20. How much lime was required to raise the pH value from the acid to the alkaline side?
Answer.

21. How much lime was required to keep it alkaline?
Answer.

22. Did you find it easier and more economical to add small amounts of lime frequently, or larger amounts less often?
Answer. 4—Large amounts occasionally. 25—Small amounts frequently.

# Operation of Trickling Filters[1]

By E. Sherman Chase[2]

It is probably true that no device for the treatment of sewage has been so generally successful and so easily operated as the trickling filter. The historical development of the filter is interesting, but not particularly pertinent to the present discussion. It may not be amiss, however, to point out the fact that the first municipal trickling filter to go into operation in this country was in Pennsylvania, at Reading, twenty years ago.

**Preliminary Treatment.**—The operation of trickling filters cannot be discussed without consideration of the preliminary treatment of the sewage. The extent of such preliminary treatment, and the care with which the devices are operated, have an important bearing upon the operation of trickling filters.

Generally speaking, the more thorough the removal of suspended solids the more satisfactory the operation of trickling filters. Preliminary treatment should be such, whether in Imhoff tanks or other types of tanks, as to prevent, in so far as possible, suspended solids, both fine and coarse, from reaching the filters. Coarse solids, such as match sticks, grease balls, fruit skins and the like, clog nozzles and in time form mats of more or less impervious material on the surface of the filters. Heavy oil and grease should also be prevented from reaching the filters. At some plants screens are located between the tanks and the trickling filters to intercept the grease solids which to some extent pass through the tanks.

With proper and efficient preliminary treatment, trickling filters are often capable of taking care of remarkably large flows of settled sewage.

**Dosing Devices.**—Most trickling filters in this country are provided with fixed spray nozzles from which the settled sewage is sprayed over the surface of the bed. Regulation of dose is usually by means of siphon tanks automatically discharging at intervals under diminishing heads. A very few small installations are provided with traveling distributors similar to those used in certain English plants. Another type of dosing apparatus consists of float- or motor-operated butterfly valves. Of this type there are also but few examples.

The siphon tank requires practically no attention. Some of these tanks are open and as a precaution against freezing are covered with planks during the winter. One difficulty sometimes encountered with open dosing tanks is the entrance of wind-blown leaves and similar material. Such material tends to increase clogging of nozzles.

[1] *Presented at Third Annual Conference, Pennsylvania Sewage Works Association, Pennsylvania State College, July 11, 1928.*

[2] *Metcalf & Eddy, Engineers, Boston, Mass.*

Frequently dosing tanks are equipped with float-operated counters for registering the number of discharges, thereby affording an approximate method for estimating the quantity of sewage treated.

Traveling distributors require oiling, adjustment, and replacement from time to time of running parts. From such data as are available, it does not appear that there are any unusual difficulties in operating this type of distributor. Butterfly valve devices also require oiling, adjustment, and replacement of parts. These devices are liable to give more trouble than tanks and siphons.

**Nozzles.**—It is not within the scope of this paper to discuss the several types of nozzles. The requirements for a satisfactory nozzle are low loss of head, uniform distribution around the perimeter of the spray, small drops, and wide spread of spray at high heads. Uniform radial distribution can be secured only by proper design of the dosing tank.

In spite of precautions, some nozzle-clogging solids are carried over to the filters. The better and more complete the preliminary treatment the less clogging of nozzles will occur. Some clogging will take place under the best of conditions, due to detachment of pieces of fungus from the walls of dosing tanks and from the inside of distribution pipes. The number of nozzles requiring attention daily ranges from a very few to practically 100 per cent.

In extremely cold weather, with cold sewage and with long intervals between doses, there may occur freezing of the nozzles. Ordinary winter temperatures give no trouble and it is only with the thermometer well below zero that freezing need be anticipated.

**Filter Media.**—Naturally the filter medium is the most important single feature of a trickling filter. It is in or on this medium that the oxidation process occurs, similar to that on the membranes lining the lungs of warm-blooded animals. It is essential that the medium be of durable material, proper size and shape. Too large material decreases the area available for the physical-biological film effecting the purification. Too small material clogs easily. Material which breaks along smooth cleavage planes compacts and clogs, while soft material may disintegrate and cement. A committee of the Sanitary Engineering Division of the American Society of Civil Engineers is working upon this matter of filter media, and a progress report has been published in Part I of the Proceedings of the American Society of Civil Engineers for April, 1928, page 243.

The continued freedom from clogging or pooling is one of the primary considerations of the operator. If such clogging occurs, due to any one of a number of causes, there are certain remedial measures which can be put into effect. Picking over or loosening the clogged portions of the bed suggests itself first. Such a measure, however, usually has but a temporary effect. Resting a bed for a week of more has been found helpful, particu-

larly where clogging is due to heavy surface growths of algae or fungi. This procedure does not give relief where accumulations of solids occur in the underdrains. Pooling is most apt to occur in the late winter or early spring. Experience at Reading, years ago, indicated that with the advent of warm weather there would develop in the filters enormous numbers of small thread-like worms, which feeding upon the gluey, bacterial jelly decreased the cohesion of the solids to the media. Furthermore, the movements of the worms acted to pry loose the clogging films so that they flushed out of the beds. In England, the insect *Achorutes-Viaticus* has been found to be a helpful factor in the unloading of trickling filters. It is the faculty of unloading which is responsible in large measure for the success of trickling filters. Experiments have been carried on at Schenectady and elsewhere to simulate this natural unloading by chlorination of the sewage applied to the filters. In a measure this appears to have been successful.

The most troublesome feature connected with trickling filter operation is the prevalence of enormous numbers of the small gray moth-fly—*Psychoda alternata*. Ordinarily these flies do not travel far from their point of origin, but occasionally under favorable conditions they may be carried considerable distances, to the annoyance of neighboring residents. These flies are by far the most prevalent in summer and are most noticeable on warm, calm, muggy days. On windy days they seek shelter. Two ways of controlling these flies have met with some degree of success, although neither can be considered fully satisfactory. The first method consists of shutting the effluent gates and allowing the filter to flood with the applied sewage. This method kills the pupæ and adult flies in large numbers, but does not entirely eradicate them nor destroy the eggs or larvæ. Furthermore, some harm is done to biological processes of the filters, and the effluent first drawn after flooding is inferior in quality. Repetition of flooding is necessary at frequent intervals and it is, of course, necessary that the filters be so designed as to permit such flooding.

Chlorination for destruction of *Psychoda* has been tried out at Schenectady, with somewhat inconclusive results. At this plant two methods have been used, one employing bleach in single concentrated doses, and the other consisting of heavy applications of liquid chlorine over a 24-hour period. Some reduction in flies has been brought about by both methods, but not complete control. It seems probable that the frequency of application was not sufficient to produce the best results. Excessive use of chlorine is to be avoided if filter efficiency is to be obtained.

Incidental to chlorination for fly control it should be noted that such chlorination appears to be of value in control of odors from the sprays.

The success of any oxidizing device depends, of course, in large measure upon the means for supplying oxygen. In the case of trickling filters this involves unobstructed circulation of air between the top and bottom of

the filter media. In some plants special ventilating cowls have been provided, but their value is doubtful. With open media and underdrains little concern need be felt as regards ample circulation. Flooded underdrains or clogged media are to be avoided. The side walls of some filters have been made of open rubble, but the value of this type of construction in so far as filter ventilation is involved, is very doubtful. The shortest path for air currents through a filter is from top to bottom and vice versa. With very fine material there is less chance for free circulation than with coarse material but the oxidation processes will take place even with a substantial depletion of oxygen in the filter atmosphere, provided some oxygen remains.

**Secondary Treatment.**—Due to the unloading of solids by trickling filters, more or less continuously and very heavily at certain times, it is generally advisable to provide secondary settling tanks or humus tanks for intercepting these solids.

It has been claimed that these solids, having been rendered fairly stable, could be discharged with the filter effluent, and that the secondary tanks are unnecessary. This argument overlooks the fact that along with the humus solids there may be discharged at times enormous numbers of worms whose dead bodies are highly putrescible. Manifestly, it would be defeating the object of the treatment plant to discharge such quantities of putrescible solids into the stream.

Several types of tanks have been employed for sedimentation of trickling filter effluents: plain shallow basins, deep Dortmund tanks, Imhoff tanks and mechanically-cleaned tanks. Except in the case of the Imhoff and mechanically-cleaned tanks, care must be taken to clean humus tanks at fairly frequent intervals, especially in summer. The sludge solids are generally somewhat flocculent and easily brought to the surface by entrained gases resulting from secondary decomposition. These solids form an unsightly, ill-smelling scum and passing out with the effluent increase the suspended solids therein. Shallow basins should be cleaned at least once a month in summer, and less frequently in winter. Wind action is beneficial in breaking up lumps of scum, thereby releasing the gas buoying up the mass, with resultant settling of the solid particles. Rising sludge is particularly prevalent during calm days of low barometer in midsummer.

The quantity of secondary or humus sludge varies with the time of year and with the degree of unloading from and digestion within the filters. The quality of secondary sludge is generally quite different from that of primary sludge. There are apt to be bodies of various organisms originating in the filters and unloaded therefrom, and particles of sand and grit from the filter media in the case of new filters. The sludge particles themselves are usually rather flocculent and gelatinous. The mass is usually of low specific gravity and of high moisture content.

The disposal of humus sludge is somewhat difficult on account of its gelatinous nature and slow drying properties. At Fitchburg, Mass., the humus sludge is pumped back to the digestion compartments of the Imhoff tanks, and there mixed and digested with the primary solids. In some places the sludge is lagooned and in others mixed with the primary sludge and applied to sludge drying beds. Due to the presence, at times, of large masses of decomposing worms, this humus sludge may be very odorous.

**Operating Results.**—The effluent of a well-operated trickling filter, after secondary settling, should have the following characteristics,—suspended solids between 20 and 40 p. p. m., a relative stability of about 7 days or more, and a 5-day biochemical oxygen demand of about 20 p. p. m. There should be a large reduction in bacteria and a conversion of organic nitrogen to nitrates.

**Care of Plant and Grounds.**—It is very important for a sewage plant operator to keep his plant and grounds in an attractive and ship-shape condition. Buildings and appurtenances should be kept in repair and well painted. Grounds should be landscaped and shrubs kept trimmed and lawns mowed. Care taken in maintenance is well repaid. It is undoubtedly true that *Psychoda* are usually not so objectionable nor odors so strong around a well-kept plant as around an untidy or ill-kept one. It is also true that it is generally easier to secure appropriations for operation for a plant in which the authorities can take pride than for one of which they are ashamed.

**Summary.**—In brief, successful operation of trickling filters calls for thorough preliminary treatment for the removal of suspended solids, fresh sewage, good distribution of settled sewage over the filters, clean nozzles, proper media and freedom from excessive pooling, and frequently cleaned secondary settling tanks. Above all, any sewage treatment plant calls for an intelligent and faithful operator with compensation sufficient to assure the right kind of a man. The best of engineering applying the best of science to the design of sewage treatment plants is of little avail if the operation is placed in indifferent, incompetent hands.

# Sewage Treatment in Europe—A Few Snapshots from an Engineer's Collection

BY SAMUEL A. GREELEY[1]

In England and Germany, much as in the United States, there is an increasing public demand for cleaner streams and for the return of fish life where pollution has driven it out. There are many sewage treatment plants, many of which have been in operation for ten to twenty or more years. Some of the newer developments of this long practice are illustrated herewith.

Figure 1 shows the oil removal tank at Essen-Rellinghausen. The purpose is to shake oily matters free from suspended solids so that more of them will separate by flotation and be trapped in the quiescent spaces at either side of the tank. The displacement period is three to five minutes and the quantity of air is given as one-tenth of the volume of sewage.

Figure 2 shows the mechanisms for operating contact aerators at the Velbert plant in the Ruhr Valley. This is a plant with a capacity for 12,000 people. The total displacement in the upper compartment of two-story tanks provides 2.5 hours of which 0.5 hour is used for the contact aerators. The quantity of air is expected to equal the volume of sewage which will require a rate of about 0.13 cubic foot per gallon.

Figure 3 shows a screen for returned activated sludge at Essen-Rellinghausen. The coarse sludge particles, comprising matches, bits of cork and similar rubbish, are screened out and returned to the influent of the two-story preliminary settling tanks. The finer and more active sludge is returned to the aeration tanks.

Figure 4 shows a machine for removing sludge from the sludge drying beds at Munich. The machine carries an open storage bin at the top and discharges the sludge into cars at the end of its travel. There are 40 sludge beds, each about 22 x 125 feet in plan. The path cleaned by the sludge machine is about 2 feet wide for each travel.

Figure 5 is a machine for removing sludge from the drying beds at Stuttgart. These sludge beds are about 300 feet long. This machine delivers the sludge to a central hopper which discharges into cars located between the sludge beds, which are some 300 feet long.

Figure 6 shows the paddle wheels at the activated sludge plant at Sheffield, England. These paddles produce a wave in the flow channel about $2^1/_4$ inches high and thus maintain a velocity sufficient to carry activated sludge. The flow time through the channels is about ten hours. With about 25 horse-power per million gallons, this plant produces a good-looking effluent from a relatively strong sewage.

[1] *Consulting Engineer, No. 6 Michigan Ave., Chicago.*

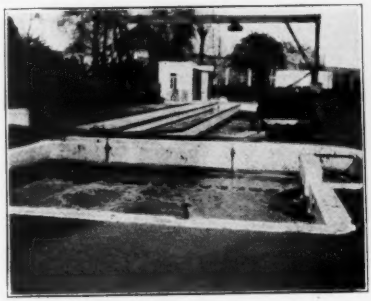


FIG. 1.

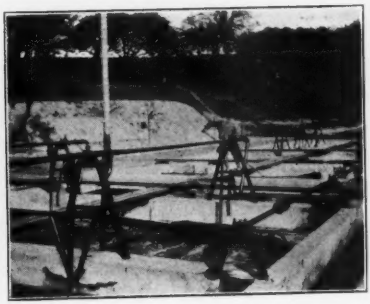


FIG. 2.

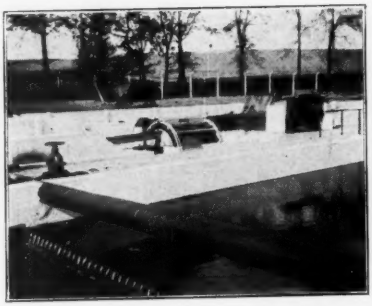


FIG. 3.

FIG. 4.

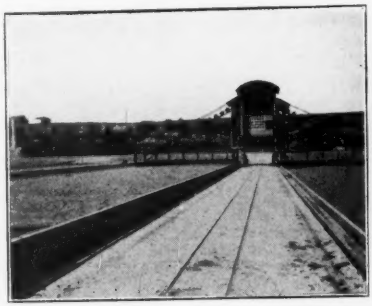


FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

Figure 7 shows the flowing-through channels in the pre-aeration plant at Birmingham, England. Originally the agitation was accomplished by paddles at the ends of channels. Recently some air has been introduced to increase the capacity of the plant, with favorable results. The picture shows the baffles designed to maintain currents in the channels and also the air piping and air bubbles.

Figure 8 shows the floating concrete covers of the digestion tanks at Birmingham. The gas from the sludge digestion is used in gas engines for power production. With a connected population of close to 1,000,000 the present installed gas engine capacity is about 600 horse-power and it is planned to increase this to about 1000 horse-power.

The visitor is especially struck by the generally fine appearance of the European sewage works. Most of them have attractive buildings and considerable planting. Except where there was little or no attempt to digest sludge, odors were not in evidence.

# Sludge and Sludge Disposal[1]

BY C. A. EMERSON, JR.[2]

The term "sewage treatment" is more inclusive, and perhaps more euphonious, than "sludge treatment" but from a practical standpoint the terms are almost synonymous.

Given treatment works functioning satisfactorily as regards removal, ripening, and disposal of suspended matters, several methods for subsequent treatment of normal municipal sewage to bring about the required degree of oxidation or the desired reduction of bacterial content can be applied with a minimum of uncertainty.

The words of the ancient mariner, "Water, water everywhere and not a drop to drink," were aptly paraphrased a few years ago when a large sewage treatment plant was described as "Sludge, sludge everywhere and not a bed for use."

Much of the research work during the past ten years has been in connection with some phase of the sludge problem. The contrast between the modern preliminary treatment processes and the old-time septic tank constructed under the Cameron patents is abundant evidence of the value of this work. It is the purpose of this paper to mention briefly some of these developments as reflected in recently designed Imhoff and separate sludge digestion tanks of moderate size.

## Preparation of Sewage

In general more attention is being given to preparation of the sewage prior to entering the tanks.

**Grit Removal.**—In the design of grit chambers facilities can be provided for continuous removal of sedimented mineral matters instead of trusting to luck that accumulations during a single storm will not exceed capacity of the settling compartments and will be removed before the next storm. Equipment is now available which separates the inorganic matter by washing, thus doing away with the troublesome problem of maintaining velocities of approximately one foot per second in the grit chamber during periods of low sewage flow.

**Bar Screens and Detritus Tanks.**—The belief that all non-mineral solids should pass to digestion compartments is apparently losing ground, for, instead of bar screens with openings from one and one-half to two inches in width, some recent designs provide mechanically-cleaned bar screens with clear spacings of only one-half inch and others include preliminary detritus tanks of 15 or 20 minutes detention capacity, from which

[1] *Presented at Third Annual Conference, Pennsylvania Sewage Works Association, Pennsylvania State College, July 10, 1928.*

[2] *Consulting Engineer, Fuller and McClintock, Philadelphia, Pa.*

settled matters are passed through fine screens with slot openings of one-eighth inch or less. This change is made in order to secure speedier and more complete digestion of solids by removal of refractory solids of slight pathogenic significance.

**Skimming.**—In order to take care of the large quantity of grease and mineral oil carried by some sewages, grease skimmers of various designs are being provided either in the grit chambers and detritus tanks or in the first compartment of the sedimentation tanks. A simple arrangement consisting of a trough with the lip an inch or so above sewage level for receiving floating matters, which are skimmed from the surface by a plank slowly dragged the length of the tank, has been found effective at a minimum cost.

## Sludge Digestion

Studies of research workers in this country and abroad have been of unquestioned value in determining the digestion capacity required for normal operation of Imhoff and separate sludge digestion tanks, but until these studies are more widely verified by operating data, it is advisable for designers to continue to provide a reasonable factor of safety, or else to arrange designs so that additional digestion space can be installed without necessity for expensive alterations.

In this paper no attempt will be made to compare the relative merits of Imhoff and separate sludge digestion tanks. The end point is the same and neither type is universally applicable. Each project must continue as a problem for special study and selection of the process should be made only after full consideration of inherent advantages and disadvantages as applied to the particular case in hand.

**Transfer of Sludge.**—Facilities for transfer of sludge from one unit to another, or for its withdrawal and return to the same unit, are of major importance. Such facilities were generally lacking entirely in earlier designs, or else were so meager that full benefits could not be secured. Development of moderate capacity, reasonably-priced pumping equipment, which will handle unscreened digesting sludge, permits the installation of these facilities even in relatively small plants. Sludge transfer facilities obviate need for reversal of direction of flow in large Imhoff tanks and permit use of triangular-shaped trough bottoms instead of multiple hoppers which are bothersome and expensive to construct. It is probable that equipment for transfer of sludge will be of especial importance in late spring, when violent digestion begins after the quiescent period of winter.

Various interesting devices for separate digestion tanks are under observation. One in Germany, which was recently described, consists of propellers suspended in vertical shafts in the digestion tanks for the purpose

of reducing acid reaction of the sludge by liberation of carbon dioxide as the sludge is circulated through the cylinders by the revolving propellers.

**Liming.**—The value of control of the reaction of sludge by liming has been fully demonstrated both in case of starting operation of new plants and in emergencies when a digestion unit begins to boil, due to change in reaction of the sludge. It is also important in the case of separate sludge tanks when it becomes necessary to pump stale sludge in the acid stage of fermentation to a tank which is not adequately seeded. As present evidence indicates there should always be well-digested sludge present to the amount of fifty times the daily sludge increment, it is probable that liming to a reasonable extent may be required at more frequent intervals than would at first appear to be the case from study of reports based upon laboratory experiments, or results of a few months, or perhaps a year's operation of a new plant.

It is of advantage to combine facilities for liming with those for transfer of sludge, so that when desired the entire mass can be treated uniformly.

**Gas Collection.**—In sizable installations, collection and burning of gas formed during digestion is worth while as a nuisance preventive, even though the gas may not be put to profitable use. In the collection and burning of the gas the dangers of explosion must ever be borne in mind. The mere provision of seals on the gas piping is not sufficient. This is particularly true in separate sludge digestion tanks where withdrawal of sludge or supernatant liquor may permit entry of air beneath the gas collectors. In such installations if provision is not made for the simultaneous addition of liquor or of sludge at rates slightly in excess of the sludge withdrawal, the gas outlet should be disconnected from the collecting system until tests prove the non-explosive character of the gas rising from that particular unit.

Scum and floating, resistant solids will quickly clog the passages leading to gas collecting domes, and provision should be made either for the removal of these matters from the tank, or for their agitation to release entrained gases and facilitate re-sedimentation.

Equipment for preventing scum from rising into the gas bells themselves is still in the developmental stage. Screens of a type found satisfactory in one installation may become clogged in a very few days in another. Elevation of gas domes or bells above the surface has been of little value in some installations where foaming has caused froth and scum to rise several feet above normal level.

Floating covers, constructed of wood, steel or concrete, are being used on digestion tanks at several places, and results available at the present time are promising. There is indication that these floating covers can be made reasonably tight against escape of gas and will do much toward lessening danger of explosive mixtures.

**Heating.**—Laboratory studies and operating results are in general agreement as to the value of conserving heat normally present in the sludge, and also as to the desirability of increasing digestion temperature during cold weather. Available information is that minimum temperatures of about 70 degrees Fahrenheit are desirable. Recent reports from abroad are to the effect that if sludge can be held above this minimum, the capacity needed for digestion is only about one-half that which would be required for a minimum temperature of 60 degrees, and about one-fourth that for a minimum of 50 degrees.

## Sludge Disposal

Addition of alum or ferrous sulphate to wet digested sludge has been tried with varying success at different plants. Green and digested sludge is being pumped several miles at a number of places here and abroad, and pipe lines of greater length than now in service have been recommended or are under construction; wet sludge is being carried to sea in barges or in tankers and dumped; sludge after being partially dehydrated by vacuum filters is dried and sold as fertilizer; but such procedures are for the most part unusual problems not encountered in the majority of installations.

**Sludge Beds.**—The present tendency follows procedure of the past, and in most cases the underdrained sand bed is the method chosen for drying sludge. Wet sludge will readily flow from 30 to 40 feet without serious drop in surface level; the unit to be supplied by one sludge outlet may therefore be as large as 30 by 60 feet. However, as it is desirable to have a considerable number of units to facilitate cleaning operation, and to permit the maximum number of uses of a bed, and as outlets and division boards of concrete or creosoted lumber are relatively inexpensive, most workers prefer units of not more than 20 or 30 feet in width, and with a distance of not over 40 or 50 feet between outlets.

The use of glass covers of the greenhouse type is increasing. Undoubtedly the number of cleanings per year can be increased through the use of these housings, but comparative operating results extending over a number of years are needed to show that the savings in area of beds compensates for the cost of the glass covers.

Some operators feel that during the summer sludge dries faster on uncovered beds freely exposed to the wind. Also that a roof or shelter of wood or corrugated iron to prevent rain from falling on the beds during the spring and fall would be as effective as the more expensive glass covers. Such construction has been used with success on small beds, the roof being built in panels which can easily be removed in summer when not needed for protection against rain.

**Disposal of Sludge.**—For removal of dried sludge from beds, some recent designs continue provision of portable tracks and small dump cars.

while in others use will be made of portable endless belts or bucket loaders of design similar to the wagon loaders successfully used for coal, sand and crushed stone.

In at least one instance sludge has been burned on the bed without objectionable odor, by building a grass fire on the surface. The resulting ash was removed at an expense estimated at about one-fourth that for unburned sludge.

The use of air-dried sludge as a fertilizer is probably increasing. In most instances the prices secured are small, but even if the sludge is taken away by farmers without any payment, it would seem to be worth while, as the municipality is saved the cost of hauling.

## Conclusions

Research work in laboratories on small samples, or results secured through operation of miniature units of sewage testing stations frequently are inconclusive. The great need today is the careful application of principles developed by research work to full-size plants, subject to hourly, daily, and seasonal variations in temperature, volume, and make-up of sewage. The almost total absence of carefully and systematically compiled operating data comparable for plants scattered throughout the country is a handicap not only to the designer but to the interested operator.

This and similar associations in sister states through coöperative action can do much to remove this handicap, and to insure continued progress in the science of sewage treatment.

# Separate Sludge Digestion Studies[1]

## The Effect of Concentration, Stirring, and Age of Raw Sludge on Digestion

BY ANTHONY J. FISCHER[2]

Investigational work, notably that carried out during the last four years, has stressed the importance of seeding, temperature, and reaction control in sludge digestion. While these are undoubtedly the most important factors, comparatively little has been said regarding the influence of sludge concentration, stirring, or the age of raw sludge on the digestion process, nor has there been much material published regarding the practical application of the control of any of these factors on a large plant scale.

In 1924, O'Shaughnessy[1,*] concluded from experiments carried out at Birmingham, England, that sludge with a solid content of about 20% would digest readily. Apparently no study had been made regarding the effect of concentration on time of digestion.

In 1924–25 in a detailed study on the course of digestion of unseeded raw sludge it was found that the material, containing 5% solids, required about 220 days for complete digestion. In subsequent work a digestion period of 200 days was found necessary for sludge containing 1.35% solids. It appeared from these comparative tests, even though the materials were not the same in each case, that time of digestion was not a direct function of concentration, and that, although the thicker sludge digested very slowly in the initial stages, the final stage was very rapid, while on the other hand the final stage was much slower in the case of the more dilute material.

In order to verify these observations a detailed experiment was run in which raw sludges containing 6, 12, and 18% solids were added daily to ripe sludge on a 2.4% dry solids basis. This was done to simulate actual plant operation. The results of this series, which was run in duplicate for 150 days, showed that there was very little difference among the various concentrations, slightly more gas being produced with the 6% sludge. The solids and volatile matter reductions were practically the same in all cases, the thickest sludge lagging behind.

The effect of solids concentrations higher than 18% was not investigated because it was considered impractical to obtain continuously such high concentrations on a plant scale without the use of special dewatering equipment such as a filter or a centrifuge.

[1] *Presented at the Sixth Annual Conference of the North Carolina Sewage Treatment Conference, Nov. 20, 1928, Raleigh, N. C. Journal Series Paper, N. J. Agr. Expt. Sta.*

[2] *Research Engineer, The Dorr Co., New York City.*

*Numbers in text refer to bibliography at end of article.

Obviously, then, it would be more economical to introduce a thickened raw sludge into a digestion tank for the following reasons: (1) The tank capacity would be cut down considerably. (2) Pumping costs would be lessened because of smaller sludge volumes to handle. (3) Less supernatant digester liquor would be returned to the settling unit. (4) Less sludge drying area would be required. (5) In the case of a heated tank, the heat loss would be materially reduced.

The question then arises, how can a sludge be readily concentrated before pumping to the digester? This can be done by allowing the sludge to accumulate in a settling tank over a considerable period and to become compact because of its own weight, or by use of a slow moving mechanism such as is commonly used for sludge removal.

The latter method is unquestionably the better because if sludge is allowed to accumulate, septic action takes place, causing scum formation and fouling of the tank effluent by decomposition of the settled sludge, with the formation of colloidal and soluble intermediate or end products. Another factor to be considered is the effect of a septic sludge on the digestion process.

Rudolfs[2] indicated that the fresher the solids are when added to a tank, the better will be the results obtained. Keefer[3] in experiments performed at Baltimore found that a high acidity developed in the settling tank sludge in a comparatively short time and concluded that rapid removal of this material was essential. Fair and Klein[4] found no progressive deterioration in unseeded raw sludge, but concluded that it seems desirable that the settling solids reach the digestion tanks as soon as possible.

In an experiment to determine the time-concentration-age relationship in sludge digestion, raw sludge was collected and different portions were seeded after various time intervals. Also, before seeding, each portion was concentrated to about 18% solids, and dilutions of 12% and 6% solids made from this thick sludge.

Results obtained from this experiment showed that the material seeded at once digested most rapidly whether the sludge had been concentrated or not. The thickened material lagged behind the dilute material only slightly. Of particular interest, however, was the fact that the concentrated septic sludge, allowed to stand before seeding until its maximum acidity had developed, required less digestion capacity than did fresh dilute sludge, even though a longer time was required in the case of the thick material. Most satisfactory results, *i. e.*, least capacity and most rapid digestion, were secured with the sludge that was concentrated to 18% solids and seeded with ripe sludge on the day collected.

An objection to the maintenance of a high solid content throughout a digester might be that a layer effect will be obtained and that the raw

sludge added will tend to form pockets, where digestion will be retarded because of a local concentration of acid end products. It might also be claimed that there will be excessive scum formation due to inability of gaseous products of decomposition to rise freely to the surface. These objections can readily be overcome by providing for adequate mixing of the raw and digested sludge and by a slow stirring action to allow release of gases and break up scum.

That stirring is beneficial for digestion was recognized as early as 1914 by O'Shaughnessy[5] who stated that several stages of digestion were beneficial, in that the sludge was thoroughly mixed in pumping from one tank to a succeeding one. Imhoff[6] also recognized the advantage of bringing the raw sludge in intimate contact with the digested sludge. Prüss[7] states that the capacity of a digestion tank at Essen-Nord has been doubled by vertically mixing the contents of the tank. Bach[8] in a series of laboratory tests showed that artificial stirring caused more rapid and more complete digestion.

In a laboratory experiment to determine the effect of different rates of stirring on digestion, a slow rate showed most beneficial results, in that scum was reduced and a denser sludge was obtained due to the release of entrained gas. This rapid release of gas (which contains an average of about 25–30% carbon dioxide) also decreased the acidity and increased the alkalinity of the sludge. No tests were made where different concentrations of sludge were stirred but it seems reasonable to assume that with a thick sludge the beneficial effect of stirring would be even more pronounced.

Taking all these factors into consideration, it appears then, from research work on a laboratory scale, that the best and most economical digestion can be secured by maintaining the following conditions: (1) a sludge temperature of about 80° F.; (2) an amount of ripe sludge equal to 20 times the weight of raw sludge added daily on the basis of dry solids; (3) a pH value of 7.3 to 7.6; (4) the addition of raw sludge in the freshest possible condition; (5) the addition of a thick raw sludge containing about 15% solids; and (6) provision for adequate mixing or stirring.

A study of operating plants over a period of two years has demonstrated that all these findings can be duplicated on a large scale and that under careful control, good operating results can be secured under the worst climatic conditions.

The Antigo, Wisconsin, plant[9] is perhaps a classic example of starting operation under adverse conditions. When this plant was put into operation the air temperature averaged about zero, minimum temperatures of 23 degrees below zero being obtained. The entire sewage flow was acid due to the introduction of waste from a local cheese factory.

Despite this, by careful control of operating conditions, excellent results were obtained, as shown by complete records kept since the plant was put into operation nearly two years ago. It is of interest to note that the gas collected has been more than sufficient to maintain a year-round sludge temperature of 80 degrees and that for the last six months the daily gas production has averaged about 1.0 cu. ft. per capita. Also, no lime additions were necessary for reaction adjustment after the initial three months of operation. Beneficial effects of the stirring mechanism are evident in that scum has been eliminated and an even gas evolution is secured. Actual test runs have shown at this and other plants of similar type that when the mechanism is stopped scum builds up and gas evolution falls off. This retention of gas by the sludge particles causes the sludge volume to expand and not only gives a thinner sludge but also forces supernatant liquor out through the overflow. Records of heat exchange show that no insulation of the heating coils by sludge caking has so far resulted. The heating system is so regulated that the in-going hot water temperature does not exceed 120 degrees Fahrenheit. The latest chemical determinations made show that the average solid content of the sludge throughout the tank is 10.7 per cent. The bottom sludge runs about 12% solids, 63% ash. The supernatant liquor is fairly clear and contains less than 0.1% total organic solids. One-third of the organic solids is contained in suspended matter, most of which is removed in the settling tank.

The greatest difficulties in sludge digestion are obtained where there are no heating facilities and no ripe sludge is available. Quite often the plant is started up in cold weather immediately after construction is completed, and the result is that sludge turns acid and accumulates in a dormant condition over the winter months. Then, when the temperature rises (and if the material is not too acid) all the accumulated material will start to gasify and foaming will result.

Conditions of this sort were encountered at Ridgewood, N. J.,[10] and at Kiel, Wisconsin.[10] At the latter plant the sludge was so acid that no gas whatever was being produced. On the addition of lime, gasification was so active that foaming resulted. The tank was then emptied and started anew, adjusting the pH value from the start. Good gasification started at once and continued through the winter months. No troubles have since been encountered, and a well digested sludge is being produced.

At Ridgewood the troubles were more pronounced in that the condition of the digester directly impaired the quality of the plant effluent. This plant, which was started in August, 1926, includes a fine screen, clarifier, plain hopper-bottomed digestion tank, and trickling filters. Initial operation required that the screenings and settled sludge be pumped to the digestion tank and the displaced supernatant liquor returned to the settling

unit. Until last year, when corrective methods were adopted, the operation of this plant was very unsatisfactory. Insufficient ripe sludge was present and excessive scum formation and foaming resulted. In order to prevent the foam from flowing out the manhole in the concrete roof the operator was forced to lower the surface level by drawing sludge about every two weeks.

To make matters worse, however, the overflow pipe extended down 4 feet below the normal liquid level, and as there were 10 feet of scum in the tank, a mixture of septic screenings and raw sludge containing 13% solids was being returned to the settling tank instead of a clear supernatant liquor. A part of this septic material accumulated in the sedimentation unit, and a part was discharged with the effluent into the trickling filters, where clogging of the nozzles and stones resulted.

To correct these conditions the following measures were employed: (1) The overflow was diverted to a sand bed, and an adjustable arrangement was added so that material at different levels could be drawn off; (2) the settling tank was completely cleared of sludge. This required thirty hours continuous pumping; (3) the top six inches of the filter stones were cleared; and (4) all scum was pumped from the digestion tank, which was then started anew after seeding with a small quantity of ripe sludge and adjusting the pH value.

Good results were noted in a comparatively short time. Removal of suspended solids increased from 52% to 74%, and the final effluent showed a remarkable improvement, high nitrates and dissolved oxygen being obtained, whereas formerly no nitrates were ever found and the dissolved oxygen content was very low. A fairly well-digested sludge was obtained in less than three months and foaming troubles were entirely eliminated. At present the scum layer is about one foot thick. The sludge is black and inoffensive and dries readily. Although lime is added whenever the pH value drops below 7.0 very little has been required.

Results obtained at these plants represent only a few cases where laboratory findings have been successfully applied. Work at a number of other plants bears out these results and indicates the extreme importance and value of laboratory experiments followed up by large-scale application. Only through work of this kind will there be a better understanding of the digestion process and simplified, improved plant operation.

**Acknowledgment.**—This work was carried out in connection with the Dorr Sewage Research Fellowship under the direction of Dr. Rudolfs. Assistance and coöperation of members of the staff of the New Jersey Sewage Investigations Laboratory, and of the operators, engineers, and city officials at the various plants visited are gratefully appreciated.

## References

[1] O'Shaughnessy, F. R., "Sewage Disposal and the Community," *Surveyor*, **66,** 1695 (1924).

[2] Rudolfs, W., "Improving Sewage Sludge Digestion," *Public Works*, **58,** 19–23 (1927).

[3] Keefer, C. E., "Changes in pH of Fresh Sewage Solids," *Public Works*, **59,** 137–8 (1928).

[4] Fair, G. M., and Klein, L., "The Effect of Age of Sewage Solids upon Their Digestibility," *Sewage Works Journal*, **1,** 14–19 (1928).

[5] O'Shaughnessy, F. R., "Utilization of Phenomena of Putrefaction. Treatment and Decomposition of Sewage," *J. Soc. Chem. Ind.*, **33,** 3–9 (1914).

[6] Imhoff, K., "Separate Sludge Digestion and Improved Mixing in Imhoff Tanks," *Eng. Rec.*, **74,** 101 (1916).

[7] Prüss, M., "A New Separate Sludge Digestion Tank with Artificial Sludge Stirring and Heating," *Gesund-Ing.*, No. 7 (Feb. 18, 1928).

[8] Bach, H., "Laboratory Experiments on the Anaerobic Decomposition of Sludge," *Gesund-Ing.*, No. 51–2 (1925).

[9] Fischer, A. J., and Quimby, F., "Sludge Heating and Gas Collection at Antigo, Wisconsin," *Public Works*, **59,** 97–101, 134–7 (1928).

[10] Fischer, A. J., "Separate Sludge Digestion Experiences," *Public Works*, **59,** 382–7 (1928).

# Industrial Wastes and Stream Pollution

## Effect of Industrial Wastes on Sewerage Systems[1]

By George S. Russell[2]

It is the purpose of this article to discuss the effect of industrial wastes upon the disposal of municipal sewage, to show how they affect a municipal sewerage system, and to present the reasons why some wastes should be totally excluded. It is not our purpose to discuss the treatment of wastes as a separate problem, except in so far as preliminary treatment may seem necessary, before the discharge of some of these wastes in the sewers may be permitted.

In the first place, the effect of industrial wastes on municipal sewage depends upon their relative volumes and analyses as compared with the volume and composition of the domestic sewage into which they discharge, and further to some extent on the time of flow from the entrance of the industrial waste to the sewage disposal plant. Ordinary municipal sewage has a diluting and neutralizing effect on acid and other industrial wastes and as a consequence it is often practicable to treat sewage containing large quantities of wastes by bacterial processes.

In general, industrial wastes should not be admitted to sewers: (1) if they contain substances which will adhere to the walls or form deposits; (2) if they contain inflammable substances; (3) if they contain steam or very hot liquids; (4) if they contain acids which will injure the material of the sewer; or (5) if they contain substances which will seriously interfere with the operation of sewage treatment works.

Under the first class come those industrial wastes containing warm fats and greases, which, upon meeting the cooler sewage, collect along the walls and tend to obstruct or reduce the capacity of the sewer. Under this class come wool scourings, and wastes from soap factories, packing houses and laundries. Also included in this class are wire mill, galvanizing, and tannery wastes, which may react with the other ingredients of the sewage to produce troublesome deposits. The grease-forming wastes should be carried through grease traps at the factory so that the grease is removed before the waste is discharged into the sewer. Retention is advantageous in order to allow the wastes to cool to the same temperature as

[1] *Presented at the 4th Annual Missouri Water and Sewage Conference, Hannibal, Missouri, Nov. 15, 16, 17, 1928.*

[2] *Consulting Engineer, Russell & Axon, Springfield, Missouri.*

the sewage. Acid wastes may sometimes be handled by providing for retention of the acid liquors and proportioning their discharge into the sewer with the flow and strength of the sewage.

Under the second class, inflammable wastes, we may include wastes from garages, shops and power houses, where crude oil or its various by-products, such as naphtha, gasoline and kerosene, find their way into the sewer. These wastes should be excluded from the sewer system by ordinance and especial care taken that the ordinance is enforced. Most of the explosions of so-called sewer gas can be traced to the presence in the sewers of some of these wastes. Besides their danger in the sewerage system, they prevent proper bacterial action at the filter plants, clog the sprays and filters and finally are detrimental to fish life after their discharge into a stream.

Class three includes those wastes which contain steam or very hot liquids. They have a deteriorating effect on sewers and on account of their excessive temperature reduce the number of bacteria and thus interfere with biological processes at the disposal plant. In this category come wastes from laundries, gas houses, and condenser water from power houses. If these wastes must be admitted to the sewerage system sufficient retention should be provided to cool to the temperature of the sewage.

In class four, those wastes which contain acids which will injure the materials of which the sewer is constructed, we may especially mention those that contain sulphur compounds, such as wastes from iron works and paper mills. These sulphates tend to form hydrogen sulphide, which will cause disintegration of concrete surfaces of manholes, sewers or sewage disposal structures. This is especially true where pressure lines or inverted siphons are necessary, where the sewers are badly ventilated, or on long flat grades where sewage becomes stale before reaching the disposal plant. The ebullition of sulphuretted hydrogen also is very obnoxious, and even where sewers are well ventilated through manholes the odors may lead to serious complaints. Where such a condition exists due to staleness of sewage before reaching the disposal plant, pre-chlorination will give excellent results. Proper study must be made to insure enough chlorine to oxidize the hydrogen sulphide and destroy the pathogenic bacteria.

Class five includes wastes which will seriously interfere with the operation of sewage disposal works. Some wastes like packing house wastes by increasing the strength of sewage increase the detention period necessary for sedimentation. Others, like wool scouring wastes, on account of the large amount of finely divided solids in suspension, materially increase the retention time.

Again, the chemical composition of the industrial wastes has a decided influence on the best period of detention of the sewage in the sedimentation tanks. Iron salts, for instance, seem to be clarified well with a detention

period of about one hour, while creamery wastes require at least forty-eight hours and some results indicate a longer period.

Most authorities agree that for strictly domestic sewage, such as combined wastes from kitchen sinks, laundry tubs, bath tubs and water closets, the proper detention period is about two hours. It is therefore obvious that the composition of the sewage should be studied in order to determine the time of detention in the sedimentation chamber.

Where wastes such as wool scourings and creamery wastes, which require much longer sedimentation periods than domestic sewage, form an appreciable portion of the total sewage flow, it is probably preferable to obtain the additional period of detention required by insisting on the construction of tanks at the industrial plant with sufficient capacity to provide the proper sedimentation in a two-hour period, after which the effluent may be emptied into the sewerage system.

Next in importance to their effect on sedimentation comes the effect of certain wastes on septic action. Some of these, like paper mill wastes, offer serious difficulties in sewage treatment on account of their antiseptic nature. Some acid wastes, present in effluents from mine drainage, wire drawing plants, and tanneries, exert an inhibiting action upon bacteria and cause considerable trouble in sludge digestion. Some others, for example creamery wastes, give an acid sludge, which increases the tendency to foaming and gives rise to bad odors. Wherever such a situation exists it may be corrected to a great extent by the addition of lime at the sedimentation tank. This will serve to keep the sludge alkaline and minimize operating difficulties.

Such wastes as those from wool scouring, soap factories, packing houses, laundries, and tanneries, which carry a large percentage of fats, are resistant to bacterial action and thus interfere with the work of the filters. The fats also diminish the value of sludge as a fertilizer. The best means of remedying this condition, as well as prevention of the danger of stoppage or reduction of capacity in the sewers, is the installation of grease traps or skimming tanks at the factory.

## Conclusions

The problem of the treatment of industrial wastes in connection with municipal sewage disposal plants may be summarized as follows:

(1) The municipality should adopt laws to prevent the discharge into the sewerage system of such industrial wastes as may be detrimental to the sewers themselves or their satisfactory operations. Wastes detrimental to the proper disposal of sewage should be controlled by requiring sufficient initial treatment before entering into the sewer, or the waste should be proportioned to the discharge of domestic sewage so that it will receive sufficient dilution to prevent difficulties.

(2) The treatment plant should be operated intelligently, including sufficient tests and records to furnish a basis for the most efficient utilization of the facilities provided.

As a final observation, it should be pointed out that a satisfactory method for handling some of these industrial wastes has not yet been found. A proper record of standard tests on various plants where these problems are encountered would materially aid investigations leading to improvements.

# Editorial

## The Centrifuge and Sewage Sludge

Widespread use of mechanical equipment for sludge collection, activated sludge treatment, and sludge digestion indicates that engineers and operators are ready and anxious to use any apparatus which may replace old-fashioned methods of sludge disposal. As yet, however, no mechanical process for dewatering settled or digested sludge has been used to any extent in the United States. Filter presses were operated for many years at Providence and Worcester for dewatering sludge from lime precipitation of sewage, but now these plants are abandoned and the standard type of filter press seems to have been discarded permanently for sewage sludge. Vacuum filters are quite satisfactory for dewatering of activated sludge and may have possibilities for dewatering of digested sludge, but even though they might be adapted to the handling of the latter it is questionable whether the cost of operation ever will be low enough to allow them to compete with sand beds.

The automatic centrifuge has for many years intrigued sanitary engineers as a possibility for dewatering of sludge. It is free from the messiness of filter presses, is entirely automatic, quite compact and of comparatively large capacity. Notwithstanding these advantages, it has not been used in this country except in experimental installations.

The Milwaukee and Baltimore tests indicated that the machine was mechanically satisfactory, but in both cases the apparently insurmountable objection was the fact that the effluent from the machine was not a clear liquid such as is discharged from a filter press, but a turbid slurry of highly colloidal solids, too putrescible to be discharged without further treatment. The insoluble solids in the effluent at Milwaukee contained the lightest, most slimy portion of the activated sludge flocs, while the digested or semi-digested solids in the effluent at Baltimore were putrescible and unsettleable. Large amounts of alum were required to clarify this liquor, thus adding to the volume and weight of sludge to be handled, aside from the expense involved.

If the centrifuge ever is to become a practical means for dewatering sludge, it is apparent that this problem of the disposal of the effluent must be solved. A combination of flocculation and re-circulation or filtration on vacuum filters might have possibilities. The outlook is not particularly encouraging on account of the very low cost of operation that

must be maintained. The Baltimore experiments indicated that if the disposal of the effluent can be accomplished at low cost the centrifuge is able to compete directly with dewatering of sludge on sand beds. It is to be hoped that in the next series of tests this obstacle may be surmounted.

---

## A Reporter's Conception of a Sewage Treatment Plant

A reporter for a Chicago daily paper wrote an article on the North Side Treatment Works at the time of its opening in October, 1928. The article is too good to be confined to Chicago readers, but space will permit only the high lights to be reprinted.

"At the north side plant, the raw sewage enters the five main pumps in the pump and blower house. Before the sewage goes into these main pumps, however, it is roughly strained by large coarse iron screens, which keep out big solid obstructions, like metal bars, large parts of machinery and wheels.

"These five main pumps are capable of handling 400,000,000 gallons of sewage a day. Driven by direct connected synchronous electric motors, they lift the sewage from the main interceptors to the seven huge blowers, forty-four feet above, which compress 250,000 cubic feet of air a minute for the aeration of the sewage in the big tanks farther on.

"The sewage, its velocity of flow decreased, next enters the grit chambers —twelve long, narrow concrete pumps in a building—where inert particles, such as sand and other non-putrefying substances, are separated from the waste. An overhead railway, across the ceiling, operates a 'hopper,' or mechanical shovel, which cleans out these pumps whenever necessary.

"The next step in the treatment is the flow into the eight preliminary settling tanks. These are huge and of equal length and width. A long-armed, many-toothed iron rake scoops away oil, grease and other coarse inorganic matter that may putrefy.

"The sewage now passes into the main building. Sludge return pumps here mix the sludge with incoming raw material. This mixture is then sent to the main aeration tanks, the heart of the plant. Three batteries, of twelve concrete double tanks each, perform the final cleansing of the sewage, which, upon entering these tanks, is inorganically refined and ready for the bacteriological process.

"The flow of the sewage in these tanks is controlled in the operating galleries near them. Air is forced up through the filtros plates, aerating the sewage, which is churned and agitated. The bevels induce a rotary motion to the whole—hence the term 'activated sludge.' By the time the

sewage is ready to leave the aeration tanks it is reduced to a stabilized mineral mass which will not putrefy.

"A fourteen-inch pipe line, fourteen miles long, carries all superfluous sludge to the west side plant, to be redigested there, and either used or dumped, an innocent loam, on waste land."

## The Digestion of Activated Sludge

The disposal of excess sludge is undoubtedly the most difficult problem in the development of the activated sludge process. In America early experiments indicated that direct application of the very wet sludge to sand beds was in most cases quite unsatisfactory because of clogging of the surface of the sand, with slow loss of water and production of odors. Some success appears to have been attained in England by use of sloping beds, but very large areas are required. It is reported that fresh activated sludge has been dried at Tenafly, New Jersey, on sloping beds in glass-covered houses, but here also large areas were required.

During the past three or four years data have been accumulating which indicate that activated sludge may be digested to a much lower moisture content, with production of an easily drainable, non-odorous sludge which will dry on sand beds. In all installations where digestion has been practised it has been the custom to mix the activated sludge with sludge from preliminary settling tanks, usually of the Imhoff type. Now Dr. Rudolfs and Mr. Heisig claim that such mixing is not essential for good digestion. Their results indicate that, from a biological standpoint, activated sludge digests rapidly and normally. Their conclusions are based mainly upon the decrease in volatile solids, and are not supplemented by records of rate of gas production.

The results obtained in the work of the Sanitary District of Chicago indicate that the organic matter in activated sludge produces less gas than is obtained from the same weight of organic matter in settled sludge or from mixtures of settled and activated sludges. The time required to reach the maximum rate of gas production was much longer at all temperatures than the seventeen days required at Milwaukee.

Further work is highly desirable on a larger scale to determine the practical application of these findings. The quality of the ripe sludge used for initial seeding apparently greatly influences the course of digestion. Unseeded mixtures digest very slowly.

One question arises concerning the degree of concentration of solids in the Milwaukee work. As removed from the tank the sludge was excessively wet, containing 95.5 per cent moisture or 4.5 per cent solids. Although this concentration of solids is almost double that of the fresh

activated sludge, still it is far less than the 12 to 18 per cent solid content of well-digested sludge from Imhoff or separate digestion tanks. Undoubtedly the use of deeper tanks would increase the concentration of the digested activated sludge, but further work is needed to demonstrate that activated sludge alone will digest to a low moisture content.

The question of the economic possibility of heating such large volumes of sludge as are produced by the activated sludge process requires investigation. Apparently heated activated sludge shows a more rapid increase in rate of digestion than is found in heated settled sludge.

It is unfortunate that the experience with mixed sludges has been obtained at the Calumet, Des Plaines, and Essen Works, and with activated sludge alone at Milwaukee. Comparative tests at the same works would be of great value.

Further investigations of this method of disposal of activated sludge will widen the outlook for the future of this process.

# Proceedings of Local Associations

## First Annual Meeting of California Sewage Works Association

**American Legion Building, San Bernardino, California**

*Tuesday, October 9, 1928*

The First Annual Meeting of the California Sewage Works Association was called to order at 9:40 a.m. on Oct. 9, 1928, by Mr. A. K. Warren, Chairman of the Organizing Committee. Mr. Warren, by way of introduction, stated that the Association was brought about by men working throughout the country; the local Association was started by Mr. Gillespie who called a meeting in San Francisco on June 11, 1928, at which fifty-one representatives were in attendance. An organizing committee was elected at the preliminary meeting composed of Mr. C. C. Gillespie of Berkeley, Mr. Philip Schuyler of San Francisco, Mr. Andrew Jensen of Fresno, Mr. O. E. Steward of Anaheim, and Mr. A. K. Warren of Los Angeles. The Committee by letter ballot elected him Chairman and he was charged with the duty of carrying the meeting through to its conclusion.

The Chairman called for the roll by the Secretary, who reported 97 members.

The Chairman then announced the names of the committeemen appointed during organization. He stated the papers on the program were arranged for by Mr. Goudey, the Chairman of the Program Committee.

The Organizing Committee appointed Mr. W. T. Knowlton and Mr. C. C. Kennedy as representatives to the Federation Board of Control.

Mr. Gillespie was called on for a report of the work of the Organizing Committee.

Mr. Kennedy was called on for a report on the National Federation. He stated that he had received two or three letters from President Emerson of the National Federation, and had been present at the meeting in Cincinnati in 1927 when the Committee of One Hundred presented its report which was the basis of the organization. The Federation was formed at the meeting of the American Society of Civil Engineers in New York City in January, 1928, when Mr. Emerson was elected President, and the various committees appointed. The most important function is the publication of contributions in the field of sewage treatment. The first Federation Journal arrived just in time for the San Bernardino meeting.

It is the intent that the Federation shall be an association for conference and for interchange of ideas and information. The large initial membership of the California Association is a creditable thing for the Pacific Coast; the highest membership in other associations within the Federation, according to last reports, was 84 as compared with 97 for California.

The Chairman brought up the matter of dues and stated that one dollar of the two dollars collected per annum went to the National Federation for the JOURNAL. A letter received from C. A. Emerson, Jr., Chairman of the Federation, advised that dues paid during 1928 carry through 1929.

The Chairman stated that our local association hoped to publish proceedings of all meetings with discussion, and additional papers which might be sent in between meetings.

The meeting was then opened for discussion and papers, other business being postponed until Wednesday morning, October 10, 1928.

The first paper was on "Water Tight Sewer Joints," by Herman P. Cortelyou. Mr. Cortelyou was unable to attend and the paper was read by the Secretary. It was discussed by Messrs. Warren, Schuyler, Koebig, Sr., Rawn, Kennedy, Knowlton, Foster, and Gillespie.

The second paper was on "Cleaning Sewers," by F. A. Barry, and was discussed by Messrs. Goudey, Loucks, Lockwood, Adams, Bowlus, Knowlton, and Foster.

The third paper, "Standardizing Sewer Pipe," by E. L. Phillips, was read by the Secretary and discussed by Messrs. Collins, Rawn, and Koebig, Sr.

The meeting adjourned for a luncheon and reconvened for a joint meeting with the Department of Engineers, Councilmen and Street Superintendents at 2 p.m., Mr. W. T. Knowlton, Chairman.

Mr. Knowlton gave a report of the Committee on Trade Wastes and Sewage Disposal which was discussed by Messrs. Gillespie, Schuyler, Kennedy, and Goudey. Mr. Gierlich moved and it was seconded and carried that a committee of three be appointed to work with the legislative committee of the League of California Municipalities. The Committee as later appointed was Mr. Postelthwaite, Mr. Chester A. Smith, and Mr. C. C. Gillespie.

Mr. Knowlton turned the chair over to Mr. A. K. Warren.

Professor Reynolds read a paper on "The Financing of Sewer Maintenance" which was discussed by Messrs. Perry, Schuyler, Warburton, and Knowlton.

Mr. Warburton moved and it was seconded and carried that a committee of three be appointed to work with the legislative committee of the League on an enabling act to cover the subject of sewer maintenance. The committee appointed later was Messrs. Warburton, Batty, and W. J. Locke.

The meeting adjourned and most of the members took an interesting trip to the new San Bernardino sewage disposal plant under construction.

*Wednesday, October 10, 1928*

The session was called to order by Chairman A. K. Warren.

Mr. Gillespie read a paper on "Sludge Digestion," which was discussed by Messrs. Perry, Knowlton, Burges, Reynolds, Kennedy, and Schuyler.

Mr. C. C. Kennedy moved, and it was seconded, that the Governing Board of this association appoint a committee to work out a standard form of plant operating reports. After discussion the motion was carried.

The Chairman introduced Mr. W. J. Locke, Executive Secretary of the League of California Municipalities, who addressed the association.

The Chairman called for the report of the combined committee on Constitution and By-Laws, and Nominations by Mr. C. C. Kennedy, Chairman.

Mr. Kennedy read the constitution and by-laws.

Mr. Warren commended the committee and asked for discussion.

Mr. Goudey suggested that the provision requiring former members to pay all back dues be amended to allow paying current dues by adding clause "Except when dues may be remitted by the Governing Board," stating that they should not be made to feel they had been expelled or rejected.

After discussion Mr. Knowlton moved that the report of committee on Constitution and By-Laws be accepted as read, and a vote of thanks be given to the committee. Motion seconded.

Mr. Warburton suggested an associate membership for material men rather than putting all members in one class as a means of avoiding possible trouble in the future.

Mr. Warren stated that this proposal had been given consideration and the committee felt that supply men entering the association would do so to get better results.

Motion carried unanimously.

Nominating Committee named the following officers:

*President:* L. B. Reynolds, Stanford University.

*First Vice-President:* F. A. Batty, 942 South Bronson Ave., Los Angeles.

*Second Vice-President:* B. J. Pardee, City Hall, Visalia.

*Secretary-Treasurer:* E. A. Reinke, Civil Engineering Bldg., Berkeley.

*Directors:*

F. M. Lockwood, City Hall, San Diego, One-year term.

A. W. Wyman, Supt. Sewage Plant, Pasadena, Two-year term.

Philip Schuyler, 114 Sansome St., San Francisco, Three-year term.

A. K. Warren, 202 Law Bldg., Los Angeles, Four-year term.

C. C. Gillespie, C. E. Bldg., Berkeley, Five-year term.

Mr. Chester A. Smith moved that the report be accepted and nominations closed. Seconded and carried.

Mr. Kennedy assumed the chair and on motion by Mr. Chester Smith, duly seconded, a unanimous ballot was ordered cast for the nominees of the Nominating Committee as officers of the California Sewage Works Association.

Mr. Warren returned as chairman.

Mr. Gillespie suggested that Mr. George W. Fuller be made an honorary member, referring to him as the "ranking dean" of sanitary engineering in this country, telling of his early work in the profession, his interest in association affairs and the great lift he gave the California Association when it was organized in June. At the suggestion of the Chair this was put in the form of a motion and seconded.

Mr. Alva Smith called attention to the fact that the constitution allows only one class of membership and stated that a motion to amend the constitution might be in order.

It was also brought out that Mr. Fuller is a member in good standing of this association.

Mr. Gillespie then suggested that he be recognized as the first member since his name heads the list in the Organization Meeting in San Francisco and that this association express its appreciation for what he has done.

Mr. Warren suggested that Mr. Gillespie make a motion to that effect, which was done, with instructions to the Secretary-Treasurer to transmit a copy of the motion to Mr. Fuller. Motion was seconded and unanimously carried.

The Chairman stated that one more matter remained and that was to accept and approve the constitution and by-laws of the Federation, as contained in THIS JOURNAL.

Moved by Mr. Koebig, Jr., seconded and unanimously carried, that the constitution and by-laws of the Federation be accepted by the California Sewage Works Association.

Moved by Mr. Goudey, seconded and unanimously carried, that the Secretary-Treasurer be instructed to write a letter to Secretary Mack of the San Bernardino Chamber of Commerce thanking him for his assistance in arranging meetings, printing, and conferences.

The business meeting was concluded and turned over to papers and discussions.

Mr. Goudey presented a paper on "Odor Control by Chlorination," which was discussed by Messrs. Schuyler, Kenney, Rawn, Reinke, Warren, and Chester Smith. This was followed by an address by William J. Lockem, Executive Secretary of the League of California Municipalities.

The session adjourned until 2 p.m., most of the members attending a luncheon discussion in a body.

Mr. Wyman read a paper "Trials and Tribulations of a Sewage Works Operator," which was discussed by Messrs. Warren and Goudey.

A laboratory demonstration of tests for settleable solids, pH, relative stability, and free chlorine was given by Mr. Reinke, and those present were given instruction in making each test.

The meeting adjourned till 9:15 a.m. Thursday, October 11, when many members and their families took a trip to Lake Arrowhead, visiting the north sewage plant in the morning and the south plant in the afternoon. Field demonstrations, sludge and scum sampling and testing were given. A delightful lunch was furnished by the Lake Arrowhead Company and the party enjoyed the rain and snow storm. The members expressed their appreciation for the courtesy shown by the Lake Arrowhead Company and their fine hospitality.

A number of members also assembled on Friday morning, October 12, and in spite of inclement weather a trip was taken to the Pomona sewage disposal plant, and through the pipe manufacturing plant of the Pacific Clay Products Company at Santa Fe Springs where the Company furnished luncheon. The courtesy and hospitality of the Pacific Clay Products Company and of the men in the organization who served as guides around the plant were appreciated by all the members present.

In the afternoon some of the party visited the Pasadena activated sludge plant and others the Harbor City plant of the Los Angeles County Sanitation District, the weather having delayed the trip so that both could not be seen. Those members attending the trips felt amply repaid for the time spent.

Respectfully submitted,
E. A. REINKE,
*Secretary-Treasurer*

---

## Fourth Annual Meeting of the Missouri Conference on Water Purification

The fourth and most successful Missouri Conference on Water Purification was held at Hannibal, Missouri, November 15–17, 1928. Interest in the program was evidenced by attendance of seventy-five members and guests, as well as lively discussions following the presentation of all papers.

Several changes were made in the constitution of the Conference. The name was changed to Missouri Water and Sewage Conference in order to indicate the present scope of interest, including municipal sewerage and sewage disposal as well as water supply. Provision was also made to accomplish affiliation of the Conference with the Federation of Sewage Works Associations.

The time and place of next year's meeting will be determined by the incoming Executive Committee. Following are the officers elected for the ensuing year:

*Chairman:* C. E. Heflin, Water Commissioner, Cameron.

*Vice-Chairman:* S. J. Duncan, Supt. Waterworks, Moberly.

*Secretary-Treasurer:* H. D. Peters, Assistant Engineer, State Board of Health, Jefferson City.

*Executive Committee:* W. V. Wier, Asst. Mgr., St. Louis County Water Company, University City; E. E. Wolfe, City Chemist, Hannibal; W. P. Britain, Supt. Waterworks, West Plains; J. N. Wells, Supt., Joplin Water Works Co., Joplin.

The revised constitution and by-laws follow:

## Missouri Water and Sewage Conference, Constitution and By-Laws

### CONSTITUTION

#### ARTICLE I

NAME

Missouri Water and Sewage Conference.

#### ARTICLE II

OBJECT

The purpose of this organization shall be to advance the theoretical and practical knowledge of its members concerning the various problems connected with the production and distribution of safe municipal water supplies and satisfactory efficient operation of sewerage systems.

#### ARTICLE III

MEMBERSHIP

SECTION 1. The members of this Conference may be either Active Members, Corporate Members, or Associate Members.

SECTION 2. An Active Member shall be a person holding a position connected with the administration, supervision, or operation of one or more waterworks or sewerage systems in the State of Missouri; a civil, mechanical, hydraulic or sanitary engineer, a chemist or bacteriologist, including those acting technically as such for, and employed by, Associate Members of the Conference; or any qualified person engaged in the advancement of knowledge relating to water supplies and sewerage in general.

SECTION 3. A Corporate Member shall be a water or sewerage board, commission, department, company, or corporation; state, district, county, or city board of health or other body, corporation, or organization interested or engaged in public water supply or public sewerage system work, and shall be entitled to one representative whose name shall appear on the roll of members and may be changed at the convenience or pleasure of the represented Corporate Member upon written request to the Secretary, and who shall have all the rights and privileges of an Active Member.

SECTION 4. An Associate Member shall be either a person, firm, or corporation, engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water or sewerage works. An Associate Member shall entitle the holder to be represented by one person on the floor at each meeting, but such representative shall not be entitled to vote.

### ARTICLE IV

ADMISSION AND EXPULSION

SECTION 1. Any person, firm, corporation, board, or department desiring to become an Active, Corporate, or Associate Member must make application for the grade of membership sought, accompanied by any initiation fees and dues as hereinafter provided, to the Secretary. All applications for membership shall be submitted to a vote of the Executive Committee. Majority affirmative vote by this Committee shall elect to membership.

SECTION 2. Any member may be expelled from this Conference for non-payment of dues or other cause by a majority vote of the Executive Committee.

### ARTICLE V

ORGANIZATION

SECTION 1. The affairs of the Conference shall be conducted by the Executive Committee, under such rules as said Committee may determine, subject to the conditions and limitations prescribed in the Constitution and By-laws of the Conference.

SECTION 2. The officers of this Conference shall consist of a chairman, vice-chairman, secretary-treasurer, and executive committee, consisting of the officers and four other members.

### ARTICLE VI

AMENDMENTS

Amendments to the Constitution may be made by a two-thirds vote of the members of the Conference present and voting at any annual meeting, providing said amendments have been approved in writing by the Executive Committee.

## BY-LAWS

### ARTICLE I

ELECTION

At each annual meeting, the Conference shall elect by ballot the officers and members of the Executive Committee. Their terms of office shall be for one year, or until their successors are elected and qualified, excepting that any office shall automatically be vacated upon the retirement of the incumbent from a position entitling him to membership, in which event the usual succession in office shall follow, the resulting vacancy to be filled by a majority vote of the Executive Committee.

### ARTICLE II

DUTIES OF OFFICERS

SECTION 1. The Chairman shall have general supervision of the affairs of the Conference and shall preside at all meetings of the Conference and of the Executive Committee at which he may be present. The Chairman shall appoint such committees as may be necessary. The Vice-Chairman shall perform any and all duties of the Chairman whenever the latter may be unable, for any reason, to perform them.

SECTION 2. The Secretary-Treasurer shall be the active business agent of the Conference and as such shall receive all dues, subscriptions, and other monies paid to the Conference. He shall pay bills against the Conference and shall make a report of the expenditures and of the funds of the Conference at the annual meetings. He shall also act as recorder of the Conference and shall maintain a complete record of its transactions.

SECTION 3. The Executive Committee shall act in capacity of directors and shall supervise and control the affairs of the Conference when the Conference is not in session. The Executive Committee shall have the power to prepare and enforce, for the conduct of the business of the Conference, by-laws not in conflict with this constitution. It shall hold at least one annual meeting during the session of each annual meeting. All ques-

tions in the Executive Committee shall be decided by a vote of the majority and four members shall constitute a quorum.

ARTICLE III

MEETINGS

An annual meeting of the Conference shall be held at a time and place designated by the Executive Committee. Due notice of the date and place of such meetings shall be sent by the Secretary-Treasurer to each member of the Conference.

ARTICLE IV

FEES AND DUES

SECTION 1. Each member shall pay annual dues of two dollars. The fiscal year of the Conference shall begin on January 1st and terminate on December 31st. Annual dues shall be payable in advance and shall be due on January 1st, the first day of the fiscal year covered by said dues. It shall be the duty of the Secretary to notify each member on or before December 31st of the amount due from said member for the ensuing year.

SECTION 2. One dollar of the annual dues collected from each member shall go to the Federation of Sewage Works Associations and entitle every member of the Conference in good standing to full membership in the Federation of Sewage Works Associations and every prerequisite attached thereto.

ARTICLE V

PUBLICATIONS

The papers and transactions of the Conference shall be published under the supervision, rules, and regulations of the Executive Committee. All publications as directed by the Executive Committee shall be supplied to members in good standing.

ARTICLE VI

AMENDMENTS

Amendments to these By-laws may be made by a two-thirds vote of the members of the Conference present and voting at any annual meeting, providing said amendments have been approved in writing by the Executive Committee.

---

## Tenth Iowa Sewage Treatment Conference and Second Annual Meeting, Iowa Wastes Disposal Association, Iowa State College, Ames, Ia., Nov. 20, 21, and 22, 1928

The Tenth Iowa Sewage Treatment Conference was held at the Iowa State College, Ames, Iowa, on November 20, 21, and 22, 1928. Eighty-three engineers, municipal officials, representatives of industrial establishments, and sewage treatment plant operators were present in addition to the student classes.

The program dealt with the major divisions of sewage treatment work, namely, plant operation, problems and difficulties of plant administration and finance, stream pollution, and the treatment of industrial wastes.

Lectures, round table discussions, and laboratory instruction made up the plan of the conference.

The following subjects were presented:

1. Sewage Treatment and the State Board of Health.
   Dr. Henry Albert, Commissioner, State Dept. of Health, Des Moines, Iowa.
2. Why Sewage Treatment?
   Ernest Boyce, Director and Chief Engineer, Kansas State Board of Health, Lawrence, Kansas.
3. Stream Pollution and Its Significance.
   A. H. Wieters, Chief Engineer, Iowa State Dept. of Health, Des Moines, Iowa.
4. Administrative Problems of Sewer and Sewage Treatment Departments.
   P. F. Hopkins, Mason City, Iowa.
5. Financing Sewage Treatment Improvements.
   H. F. Ferguson, Chief Sanitary Engineer, Dept. of Public Health, Springfield, Ill.
6. Financing the Operation and Maintenance of Sewage Treatment Plants.
   Ernest Boyce, Chief Engineer, Kansas State Board of Health, Lawrence, Kansas.
7. Improving the Status and Qualifications of Sewage Treatment Plant Operators in Iowa.
   A. H. Wieters, Chief Engineer, Iowa State Dept. of Health, Des Moines, Iowa.
8. Sewage Treatment for Small Municipalities.
   H. N. Jenks, Assoc. Prof., Sanitary Engr., Iowa State College, Ames, Iowa.
9. Why Septic Tanks Go Bad.
   Howard R. Green, Pres., Howard R. Green Co., Cedar Rapids, Iowa.
   Earle L. Waterman, Prof. Sanitary Engineering, University of Iowa, Iowa City, Iowa.
10. Operating Experiences with Imhoff Tanks.
    Earle L. Waterman, Prof. of Sanitary Engr., University of Iowa, Iowa City, Iowa.
11. Sludge and Its Disposal in Small Sewage Plants.
    Frank Bachmann, Sanitary Engineer, The Dorr Company, Chicago, Ill.
12. The Status of Sewage Treatment in Iowa.
    W. W. Towne, Ass't. Sanitary Engineer, Iowa State Dept. of Health, Des Moines, Iowa.
13. Disposal of Creamery and Sugar Wastes.
    Dr. Max Levine, Bacteriologist, Engineering Experiment Station, Iowa State College, Ames, Iowa.
14. The Value of Routine Tests in Sewage Treatment Plant Operation.
    Jack J. Hinman, Jr., Associate Prof., Sanitation, State University of Iowa, Iowa City, Iowa.
15. Keeping the Sand Filter in Working Order.
    Howard R. Green, Pres., Howard R. Green Co., Cedar Rapids, Iowa.
16. The Sprinkling Filter—Its Operating Problems.
    Fred G. Nelson, Sanitary Engr., Currie Engineering Co., Webster City, Iowa.
17. Getting the Plant into Shape for Winter Operation.

Lafayette Higgins, Lafayette Higgins and Son, Des Moines, Iowa.

18. Sewage Treatment Plant Difficulties and Experiences.
Discussion by Operators.

19. How Can We Dispose of Industrial Wastes?
C. H. Currie, Pres., Currie Engr. Co., Webster City, Iowa.

20. Improving the Appearance of the Plant and Grounds.
A. E. Holmes, Civil and Landscape Engineer, Lake View, Iowa.

At the call of Pres. C. H. Currie, the Iowa Wastes Disposal Association held its second annual meeting on November 21st, at Ames.

The usual order of business was followed: Under the head of new business President Currie recommended that the Iowa Association formally affiliate with the Federation of Sewage Works Associations. After full discussion a motion was unanimously passed favoring affiliation. Fifty-six names were by motion placed on the charter roll of membership.

Legislation needed in Iowa on sewage treatment matters was discussed and a legislative committee composed of Earle L. Waterman, Chairman, Howard Green, Harry N. Jenks, Hans V. Pedersen, and A. H. Wieters was appointed.

A motion was made and unanimously carried that the offices of the Iowa Association for the present year be retained for the ensuing year.

They are as follows:

*President:* C. H. Currie, Webster City.

*Vice-President:* Jack J. Hinman, Jr., Iowa City.

*Secretary-Treas.:* Lindon J. Murphy, Ames.

The Iowa Representatives on the Board of Control of the Federation are: Max Levine, Ames; Jack J. Hinman, Jr., Iowa City.

---

## North Carolina Conference on Water Purification and Sewage Treatment

## Sixth Annual Meeting

## Raleigh, November 19, 20 and 21, 1928

The Sixth Annual Conference on Water Purification and Sewage Treatment was held jointly with the eighth annual convention of the North Carolina Section, American Water Works Association, at the Sir Walter Hotel in Raleigh on November 19, 20 and 21, 1928. The enthusiasm which has been characteristic of the meetings in the past was even more in evidence on this occasion. Representatives were present from 15 states of the South, East and Middle West, and the registration reached 269, a new record. Of this number, 177 were men actually engaged in the design, construction, operation and management of sewerage and sewage

treatment works, 67 were commercial representatives of manufacturers and dealers, and 25 were visitors. About 25 exhibits were attractively arranged on the mezzanine floor of the Sir Walter, which evoked the greatest interest. Chairman J. S. Whitener presided over the sessions of the Conference. The City of Raleigh was host at a complimentary dinner on November 19, and the annual banquet was held on the evening of November 20.

Papers on sewage disposal and stream pollution presented during the convention were the following:

"Some Notes on Present-Day Sewage Disposal Processes and Problems," by Wm. M. Piatt, Consulting Engineer, Durham.

"Water Resources Investigations in North Carolina," by Thorndike Saville, Chief Engineer, N. C. Dept. of Conservation and Development, Chapel Hill.

"Disposal of Industrial Wastes," by Dr. John D. Rue, Director of Research, Champion Fibre Co., Canton.

"Preliminary Operating Results of the Charlotte Activated Sludge Plants," by E. G. McConnell, Sanitary Engineer in Charge of Plants, Charlotte.

"Separate Sludge Digestion Studies," by Anthony J. Fischer, Research Engineer, The Dorr Co., New York.

"Experimental Studies on the Treatment of Combined Sewage and Textile Wastes," by Albert M. Worth, Sanitary Engineer in Charge of Plants, Durham.

"Biochemical Oxygen Demand Reduction by Chlorination," by H. G. Baity and F. M. Bell, University of North Carolina, Chapel Hill.

All of these papers created lively interest, and the program was supplemented by informal round-table discussions.

On the evening of November 20 a meeting was called of all persons interested in sewage disposal problems to consider the advisability of reorganizing the Conference. In order to conform strictly to the policies and constitutions of both the American Water Works Association and the Federation of Sewage Works Associations, and to prevent any possible future conflict with either organization, it was deemed advisable to abolish the Conference on Water Purification and Sewage Treatment, which has been a subsidiary organization of the N. C. Section, A. W. W. A., and also the participating agency of the Federation, and form in its stead a new and independent organization to be known as the North Carolina Sewage Works Association. After lengthy discussion, such an organization was formed, which becomes the North Carolina member of the Federation. It will meet jointly with the N. C. Section, A. W. W. A., in annual convention, and handle all topics of sewage disposal and stream pollution.

A constitution conforming closely to that of the Federation was adopted, and the following officers and committees were elected for the coming year:

*President:* McKean Maffitt, Supt. Water and Sewer Dept., Wilmington.

*Vice-President:* P. J. Dishner, Supt. Water and Sewer Dept., High Point.

*Secretary-Treasurer:* H. G. Baity, Assoc.-Prof. of Sanitary and Municipal Engineering, University of North Carolina, Chapel Hill.

*Editor:* E. G. McConnell, Sanitary Engineer in Charge of Plants, Charlotte.

*Representatives on Federation Board of Control:* H. E. Miller, Chief Engineer, State Board of Health, Raleigh; Wm. M. Piatt, Consulting Engineer, Durham.

*Executive Committee:*
H. G. Baity, Chapel Hill
J. O. Craig, Salisbury
P. J. Dishner, High Point
C. G. Logan, Waynesville
McKean Maffitt, Wilmington
E. G. McConnell, Charlotte
H. E. Miller, Raleigh
W. E. Vest, Charlotte.

*Publication Committee:*
E. G. McConnell, Charlotte
W. E. Vest, Charlotte.

*Sewage Works Financing:*
H. E. Miller, Raleigh
Wm. M. Piatt, Durham
C. W. Smedberg, Greensboro.

By arrangement with the Publication Committee of the N. C. Section, A. W. W. A., the papers and proceedings of the local association will be published jointly in their journal and sent to the 1500 engineers, water and sewage works superintendents in the Southeast who are on their mailing list. Such material will also be made available to the national *Sewage Works Journal.*

Resolutions were adopted expressing the gratitude of the Association to the City of Raleigh and its officials for their hospitality and entertainment, to the many out-of-state visitors for their splendid contributions to the program, to the manufacturers whose coöperation has assisted so materially in the success of the meetings, and to the press representatives whose publicity carried to the people of the state an interpretation of the vital enterprises in which the Association is engaged.

The 1929 convention will be held at the Sheraton Hotel, High Point, N. C., on November 4, 5, and 6.

# Reviews and Abstracts

## Studies on the Activated Sludge Process

ABSTRACTED BY C. C. RUCHHOFT

The annual report of the Rivers Department of the City of Manchester, England, for the year ending March 28, 1928, contains some very interesting studies on the activated sludge process. These studies were made by W. J. Lockett, M.S., Research Chemist, under the direction of Edward Ardern, D.Sc., Consulting Chemist.

### Microbiological

The first was a microbiological study to determine (a) the types of protozoa occurring in activated sludge under different working conditions, (b) the influence of protozoa on the phenomenon of bulking, and (c) the function of protozoa in the purification process. The protozoal characteristics found in numerous examinations of sludges of various qualities are shown in the following table:

| | Protozoal Classes and Relative Abundance | | |
|---|---|---|---|
| Condition of Sludge | Amoebæ (Sarcodina) | Flagellates (Mastigophora) | Ciliates (Infusoria) |
| (*a*) Bad | Preponderance | Preponderance | Very few |
| (*b*) Unsatisfactory | Many | Many | Few |
| (*c*) Satisfactory | Few | Few | Preponderance |
| (*d*) Good (Nitrification well established) | Rare | Very few | Preponderance |

While the actual numbers of organisms were not determined it was found that sludges *a*, *b* and *c* were more thickly populated than *d* and that sludge from domestic sewage was richer in protozoa than sludges from sewages containing inhibitory industrial wastes.

The influence of protozoa on the phenomenon of bulking was studied in two glass vessels of 2 to 3 liters capacity equipped with diffusers and operated on the fill-and-draw principle. A nitrifying sludge containing relatively few protozoa was added to each vessel and in addition about 600 large clusters of Carchesium, freshly isolated from activated sludge, were added to the second. Both sludges were treated with successive volumes of sewage for several weeks. At first only 2 fillings per day were made but later the number was increased to four and five. When sludge was wasted as many as possible of the colonies of Carchesium contained in the wasted

sludge were re-isolated and returned to the second aeration vessel. The volumes of air used were as nearly as possible the same.

The results for the period of this experiment (130 days) showed that during this time the sludge in the first vessel contained large numbers of Aspidisca but only a few minute colonies of Carchesium while the second vessel contained a great preponderance of Carchesium and Aspidisca. There was very little difference in the percentage of sludge settling in either bottle, measured after one hour. It was concluded that Carchesium in abundance had practically no effect on the settling quality of sludge.

The function of protozoa in the purification process was studied by operating two aerating vessels, as previously described, in parallel. In one of these vessels the protozoa were killed by aeration with toluene vapor. These sludges were then treated with activated sludge effluents free from active protozoa, and later with raw sewage free from protozoa, with suitable aeration periods. The experiments were continued as long as the toluened sludges remained free from active protozoa (8 to 10 days).

The results from three experiments indicated that the treatment with toluene vapor affected the physical properties of the sludge to some extent and that the effluent from the first few fillings was more turbid. After a few days, effluents of similar quality, as determined by chemical analysis, were obtained from both the protozoa-free sludge and the control sludge. As long as the toluened sludges remained free from protozoa the effluents were always less clear than those from the control. In two experiments when the effluents from the toluened sludge became perfectly clear flagellates were found in the sludge.

The conclusion reached from these experiments was that protozoa play no important part in the process of purification by activated sludge, although it is possible that they facilitate the production of a more highly clarified effluent.

## Effect of Iron Compounds on the Treatment of Sewage by the Activated Sludge Process

In the first of the experiments with iron, studies were made of the effect of various doses from 10 to 100 p. p. m. of iron as ferric chloride upon the purification process in activated sludge treatment. The sludge used was capable of producing clear and satisfactory effluents but no nitrification. Sewage was obtained from the Withington works. Aeration vessels as previously described were used in these experiments. One vessel contained the control sludge, to which successive volumes of untreated sewage were added; the others contained the same sludge, to which successive volumes of sewage containing the required amounts of iron were added. A six-hour cycle of operations comprising three hours of aeration, three hours of settling, decantation of purified effluent, and refilling with sewage, was continued

for several days. At the end of the experiment with iron-treated sewage all sludges were treated with sewage without chemicals for several days to determine the effect of the added iron salts upon the normal properties of the sludge. Analyses of the effluents after various aeration times were made. Typical results of three runs are shown in Table I. In later runs up to 100 p. p. m. iron was added.

TABLE I

EFFECT OF "FERRIC" IRON AS FERRIC CHLORIDE ON PURIFICATION OF SEWAGE BY THE ACTIVATED SLUDGE PROCESS

Results in Parts per Million

| | | Series 1a—Filling No. 49 Effluents | | | | | | Series 1b—Filling No. 16 Effluents | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | After 40 Minutes Aeration | | | After 3 Hours Aeration | | | After 3 Hours Aeration | | |
| | Sewage | No Reagent | 10 Parts Fe | 20 Parts Fe | No Reagent | 10 Parts Fe | 20 Parts Fe | No Reagent | 30 Parts Fe | 40 Parts Fe |
| Four hrs. $O_2$ absorption | 52.6 | 10.0 | 7.7 | 6.3 | 7.1 | 5.4 | 4.9 | 6.6 | 4.9 | 4.0 |
| Free and saline $NH_3$ | 35.7 | 32.1 | 33.6 | 32.1 | 28.6 | 29.3 | 29.3 | 16.4 | 17.1 | 14.3 |
| Albuminoid ammonia | 9.4 | 3.6 | 3.1 | 2.5 | 2.5 | 2.1 | 2.0 | 1.6 | 1.5 | 1.35 |
| Nitrite and nitrate (as $NH_3$) | .. | .. | .. | .. | 0.7 | 0.7 | 0.7 | 0.2 | 0.3 | 0.3 |
| Alkalinity (as $CaCO_3$) | 250 | 240 | 230 | 220 | 240 | 210 | 190 | 200 | 110 | 80 |

The results show that superior effluents were obtained when from 10 to 60 parts per million of iron as ferric chloride were used. The effect was roughly proportional to the amount of iron used. When the iron treatment of the sewage was discontinued the effluents continued to be slightly superior to the control for a short period but usually there was little difference. With 100 parts per million of ferric iron good results were also obtained, but in this case after the iron treatment of the sewage was discontinued turbid effluents were obtained. This effect was attributed to a periodic lowering of the pH of the mixed liquor below the neutral point.

Similar experiments showed that iron as ferrous sulphate also facilitated purification, although it was not as effective as ferric iron. Fifty p. p. m. of iron as ferrous sulphate was slightly less effective than 20 p. p. m. as ferric chloride.

The effect of ferric and ferrous iron treated sewage added to activated sludge capable of nitrification was also studied. In this experiment 50 p. p. m. of ferric iron as ferric chloride and 20 p. p. m. as ferrous sulphate were used. When judged by the four-hour oxygen absorbed and the albuminoid ammonia tests the results were similar to those of the preceding experiments. No definite evidence was obtained to show that the iron

treatment helped nitrification. Sewages with and without the iron reagents were nitrified at about the same rate.

Some studies were made to determine which of several theories that have been proposed as an explanation of the beneficial effect of iron salts in the purification process were correct. No evidence was found to support the theory that iron compounds acted as oxygen carriers. The possibility that the partially clarified liquor immediately resulting from addition of iron salts was more readily oxygenated than the colloidal mixed liquor in the control was considered. However, the rate of oxygenation of clear water was no higher than that of colloidal solutions such as dilute starch solution. It is possible that the lowering of the pH of the mixed liquor due to addition of the iron solution may have a beneficial effect, but when the pH was lowered to precisely the same extent by the addition of acid no beneficial effect on the rate of purification was obtained. Experiments in which freshly precipitated iron hydroxide was introduced with the sewage treated also showed a marked increase in the rate of removal of oxidizable matter and supported the idea that the beneficial effect is due to the precipitate formed by the sewage compounds and the reagent.

From a practical standpoint these tests indicated that the addition of 50 p. p. m. iron, equivalent to two-thirds of a ton of ferric chloride (100 per cent $FeCl_3$) per million gallons (Imp.) would reduce by one-half the average aeration period required for Withington sewage. While this amount is prohibitively costly, the experiments indicated that this problem is worthy of more extended consideration, particularly in connection with the treatment of strong or "difficult" sewages.

---

## Research on the Mechanism of the Activated Sludge Process

By Adolf Seiser

*Gesundh. Ing.*, **51**, 253 (1928); **51**, 273 (1928)

Abstracted by Dr. Arthur Lederer

This article is one of the few since the advent of the activated sludge process which deals with the underlying scientific principles rather than with the practical application. More of such research is needed for the purposes of better understanding and improvement of this process of sewage treatment.

The experiments were carried on by the author in the laboratory. The activated sludge was obtained by the fill-and-draw system. The air was not measured but the experiments were sufficiently controlled to be of

real value. The object was principally to determine the fate of various substances present in the sewage, or formed in the course of decomposition. In order to study the fate of these substances they were added to the sewage in pure form and the catabolic products studied by withdrawing samples from time to time during activation. The substances examined were: horse serum, beef serum, peptone, asparagin (as a representative amino acid), urea, ammonium sulphate, glucose and colloidal siliceous matter (quartz sand).

The author employed for the aeration glass tubes 150 cm. high and 7 cm. in diameter. The tubes had a conical bottom. The air passed through a glass tube at the end of which was fastened an aeration cone of burned clay—a material which is probably comparable with filtros in porosity. The escaping air was passed through N/10 $H_2SO_4$ in order to determine by titration the loss of basic substances, such as ammonia. Paraffin oil was added in the protein experiments for the purpose of preventing foaming. Only fully activated sludge was used and a record was kept of the temperature prevailing at each experiment.

The first test, in which beef serum was used, extended over a period of 13 hours. Samples of settled effluent were analyzed after 1, 4 and 7 hours. Aeration carried off only traces of ammonia but adsorption removed a large proportion of it during the first hour. Biologic activity was responsible for further purification. The author believes that the process is one in which physico-chemical as well as biological factors play a part but his results indicate that adsorption capacity of the sludge is largely exhausted after the first one-hour period. Serum nitrogen goes into biologic solution to the extent to which it is fixed by adsorption. The author's observation that too much aeration is inconsistent with satisfactory clarification has, of course, been noted by many others. The reduction of carbonaceous matter, as measured by "oxygen consumed," paralleled the reduction of organic nitrogen. Experiments in which horse serum and ferrous sulphate were added showed a more rapid clarification in the samples to which the iron salt was added. The initial iron content was 12.2 p. p. m. After 5 hours aeration 99% had disappeared. In the control, in which iron was added to the sewage containing beef serum but no sludge, the initial quantity of iron was still present after 5 hours' aeration; here the serum acted as a protective colloid. No reference is made by the author to a possible catalytic activity of the iron salt present. On substituting globulin for albumin similar results were obtained as far as adsorption and biolysis are concerned.

In another experiment using beef serum in the concentration uniformly applied by him, Seiser showed that 38 per cent of the organic nitrogen was actually adsorbed after 1 hours' aeration. With increasing quantities

of serum the absolute adsorption of nitrogen increased but the percentage adsorption decreased. It is interesting to note that the adsorption diminished with the split products of protein decomposition. For instance, peptone proved to be decomposed biologically more easily than serum, but there was less adsorption. With asparagin—a representative amino acid—the adsorption was still less. The percentage adsorption was as follows:

| | |
|---|---|
| Serum | 56.1% |
| Peptone | 29.6% |
| Asparagin | 6.1% |

It is also interesting to note that the decomposition of peptone and asparagin took place more rapidly in the presence of a nitrogen-free source of carbon such as dextrose. The addition of dextrose to tubes containing asparagin favored the conversion of nitrogen into bacterial protein. The absence of dextrose favored the formation of ammonia.

In the first two hours of aeration in the presence of asparagin twice as much dextrose was removed by adsorption as was removed by biological decomposition. Dextrose was adsorbed to a much greater degree than asparagin. Less urea was adsorbed than asparagin, and with ammonium sulfate the adsorption was only slight. On determining the effect of the activated sludge process upon colloidal quartz Seiser found that three hours of aeration resulted in extensive clarification. The author points out that a fluctuating salt content up to the limit of physiological concentration does not interfere with the process to any extent. The effect of the activated sludge process is primarily due to the sludge and its organisms. A purely physical effect is only of slight importance for colloids and negligible for crystalloids.